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NATURAL REVEGETATION OF RANGE LANDS BASED UPON GROWTH REQUIREMENTS AND LIFE HISTORY OF THE VEGETATION

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INTRODUCTION

Ideal range management would mean the utilization of the forage crop in a way to maintain the lands at their highest state of productiveness and at the same time afford the greatest possible returns to the stock industry. To maintain the maximum productivity, the annual herbage crop must be used in a manner which will not retard the growth or prevent the perpetuation of the most desirable forage species. On the other hand, if the stock industry is to receive the greatest possible returns at all times, the annual forage crop should be used when it is most needed and when the herbage is palatable and nutritious.

It is obvious from this that the requirements of the vegetation and the requirements of the stock are to a great extent antagonistic. Hence, unrestricted grazing, without regard for the vegetation or the locality, eventually results in decreased productivity, and often in denudation.

The decline in carrying capacity of our western grazing lands was brought about in part by injury due to trampling, but perhaps in greater part by premature grazing and overstocking. The growing herbage might be called a laboratory where plant nutrients are prepared, and the repeated removal of the foliage year after year during the fore part of the growing season means the destruction of this laboratory, which in turn means lack of nourishment for the vegetation, resulting in lowered vitality and an inability to produce seed.

The easiest way to overcome the deteriorating effect of premature grazing and overstocking, as well as of trampling, would be, of course, to eliminate grazing entirely. Obviously, however, such a procedure would be impracticable from the standpoint of the stock industry. Since this is so, the best means of solving the problem in a scientific manner is to

approach it as similar problems in farm practice are approached—that is, (1) by a careful study of the vegetation making up the forage crop, (2) by a study of the natural factors upon which depends the success or failure of the forage crop and its perpetuation, and (3) by a study to find a method of grazing which will both fully utilize the forage and at the same time protect it from deterioration.

Such studies were undertaken by the Forest Service in cooperation with the Bureau of Plant Industry during the spring of 1907 in the Wallowa Mountains of northeastern Oregon. While the intensive investigations were confined in the main to this one grazing region, the results have been applied elsewhere with success, notably in the Hayden National Forest in Wyoming. It is possible, of course, that the reproductive capacity of various forage plants may vary in different localities and also that there may be a difference in the behavior of plants on ranges grazed by sheep and those grazed by cattle and horses, any of which may affect the measure of success obtained by deferred grazing, but not the principles involved in the system.

The purely experimental studies were continued throughout the seasons of 1907, 1908, 1909, and 1910 and were followed by a practical application of the principles evolved to range management on lands within the Wallowa National Forest.

The system developed as a result of the studies—a combination of deferred and rotation grazing—is now being applied with minor variations to range lands throughout the National Forests, and promises to be of the greatest value in bringing about the efficient utilization of the forage resources.

This article gives in full the data upon which the new system is based. The area where the intensive studies were carried on is first described. Following this are given the life histories of the important forage species, including growth requirements and the factors influencing the establishment of reproduction. This in turn is followed by a discussion of the relative merits of different systems of grazing. Finally there is presented a rational and economical grazing system based upon the requirements of the forage plants and of the stock industry

TOPOGRAPHY AND SOIL

The Wallowa National Forest, within which the studies were carried on, is a region of high mountains, very irregular and broken. From the Grande Ronde and Wallowa Valleys, which bound the forest at about 3,000 feet elevation, the mountains rise to from 6,000 to 9,500 feet. On the upper reaches of the numerous domes, above the limits of forest growth, snow often remains throughout the summer. In this group of high, snowy peaks, within a radius of about 3 miles, rise nearly all of the streams from which the stock of the region are watered.

The forest exhibits three principal rock formations: Basaltic, granitic, and limestone. These give rise to as many different soil types, which in turn very largely determine the character and density of the vegetation. The best and most luxuriant vegetation is found upon the basaltic soils, which cover the greater part of the region, the comparatively recent lava flows from which they originate having buried the original formationsi n some places to a depth of several hundred feet. They are porous and very friable, admit of about average percolation, and retain water well. The granite and limestone soils, on the other hand, are poorly decomposed and lose moisture rapidly through percolation and evaporation. In consequence the vegetation is usually sparse, only the more drought-resistant plants being able to establish themselves. The limestones, mixed with shales, are the oldest and most restricted of the three formations. The granites, which are of a later period, form the peaks, crests, and soils of the very highest mountains.

CHARACTER AND DISTRIBUTION OF THE VEGETATION

Within the great altitudinal range between the lower valleys and higher mountains of the region wide differences naturally exist in the physical conditions which govern plant growth, and therefore in the character and composition of the growth itself. On the other hand, physical and climatic conditions, and consequently the vegetation, are strikingly similar within certain altitudinal limits, making it possible to divide the region into four climatic zones. Following Merriam's classification[1] these are:

Transition zone (yellow-pine association)	3,000 to 4,500 feet.
Canadian zone (lodgepole-pine association)	4,500 to 6,800 feet.
Hudsonian zone (whitebark-pine association)	6,500 to 8,500 feet.
Arctic-Alpine zone (Alpine-meadow association)	above 8,000 feet.

The altitudinal limits of these zones are not absolutely marked, since altitude does not wholly determine the character and composition of the vegetation. Hence, the limits given above should be considered only approximate for a given locality in this latitude.

THE TRANSITION ZONE.—The Transition zone contains a number of coniferous tree species, the most characteristic being western yellow pine (*Pinus ponderosa*). Toward the upper limits of the zone yellow pine gives way to Douglas fir (*Pseudotsuga taxifolia*) and lowland fir (*Abies grandis*). As a rule, the timber is open, with considerable undergrowth of average palatability and nutritiousness, if grazed relatively early (Pl. XII).

Among the most characteristic and abundant herbaceous species is pine-grass (*Calamagrostis rubescens*). Other species which furnish a large

[1] Merriam, C. Hart. Life zones and crop zones of the United States. U. S. Dept. Agr., Div. Biol. Survey, Bul. 10, 79 p., 1 map. 1898.

part of the herbage on the lower, sparsely timbered lands are big bunch-grass (*Agropyron spicatum*), little bluegrass (*Poa sandbergii*), big blue-grass (*Poa scabrella*), and blue bunch-grass (*Festuca arizonica*). Germination and growth begin in the most exposed situations during the first week in April, and early in May the vegetation shows everywhere throughout the zone. Stock are usually not admitted before May 15.

CANADIAN ZONE.—The Canadian zone is characterized by lodgepole pine (*Pinus murrayana*), the predominant tree of the region. In many places the timber is so dense that there is little or no undergrowth of vegetation. Only the most tolerant shrubs and herbs can exist in the subdued light under the heavy timber, and such lands are of practically no value for grazing. In other places extensive areas of lodgepole pine have been burned over. Sometimes reproduction is established promptly, but where fire has consumed most of the organic matter in the soil, the reestablishment of vegetation of any kind is slow. Among the forerunners in the invasion of permanent species, fireweed (*Chamaenerion angustifolium*), a valuable sheep forage, and pearly everlasting (*Anaphalis margaritacea*), a plant of no forage value, are most common. Both growth and grazing begin in this zone fully 20 days later and end two weeks earlier than in the Transition zone below.

HUDSONIAN ZONE.—The Hudsonian zone, in contrast with the lands immediately below it, is open in character, the timber growing sparingly and in clumps. The predominating vegetation consists of grasses intermixed with various other palatable plants, as shown in Plate XIII, figures 2 and 3.

This zone probably covers a larger area than the two lower zones combined and supports most of the sheep permitted in the Wallowa Forest during the summer growing season. On account of the demands made upon this desirable range and because of the character of the forage, the Hudsonian zone has suffered more serious depletion than any other, and it was here that the most intensive study of revegetation was made.

The trees of the Hudzonian zone, most of which extend to the normal timber line, are Alpine fir (*Abies lasiocarpa*), whitebark pine (*Pinus albicaulis*), Engelmann spruce (*Picea engelmanni*), and mountain hemlock (*Tsuga mertensiana*). Whitebark pine is the most characteristic species, and its altitudinal distribution is so clearly marked that one can be certain wherever it is met that the conditions there are those of the Hudsonian zone. The timber grows in small, dense clumps, precluding an undergrowth of any but the most tolerant species.

Aside from the timber, vegetation is distinctly herbaceous and consists mainly of grasses and nongrasslike plants, commonly termed weeds. While a great many of the species are grazed to a limited extent at one time or another during the season, about 40 furnish 90 per cent of the

range forage. These, arranged in the order of their local forage value, are:

Mountain bunch-grass (*Festuca viridula*).
Little bluegrass (*Poa sandbergii*).
Short-awned brome-grass (*Bromus marginatus*).
Western porcupine, or needle grass (*Stipa occidentalis*).
Smooth wild rye (*Elymus glaucus*).
Tufted hair-grass (*Deschampsia caespitosa*).
Wild celery (*Ligusticum oreganum*).
Onion grass, or mountain bluegrass (*Melica bella*).
Red bunch-grass (*Agropyron flexuosum*).
Mountain wheat-grass (*Agropyron violaceum*).
Yarrow, or wild tansy (*Achillea lanulosa*).
Spiked trisetum (*Trisetum spicatum.*)
Butterweed (*Senecio triangularis*).
Coneflower (*Rudbeckia occidentalis*).
Wild buckwheat (*Polygonum phytolaccaefolium*).
Alpine timothy (*Phleum alpinum*).
Horsemint (*Agastache urticifolia*).
Wood rush (*Juncoides glabratum*).
Nuttall willow (*Salix nutallii*).
Fireweed (*Chamaenerion angustifolium*).
Mountain dandelion (*Agoseris glauca*).
Mountain onion (*Allium validum*).
Little needle grass (*Stipa minor*).
Wild onion (*Allium platyphyllum*).
Wild onion (*Allium collinum*).
Tall swamp-grass (*Carex exsiccata*).
False hellebore (*Veratrum viride*).
Valerian (*Valeriana sitchensis*).
Alpine redtop (*Agrostis rossae*).
Blue beardtongue (*Pentstemon procerus*).
Elk-grass (*Carex geyeri*).
Skunkweed, or Jacob's-ladder (*Polemonium humile*).
Sheep sedge (*Carex illota*).
Reed-grass (*Cinna latifolia*).
Woolly weed, or woolly hieracium (*Hieracium cynoglossoides*).
Onion grass, or mountain bluegrass (*Melica spectabilis*).
Wire sedge (*Carex hoodii*).
Tall meadow grass (*Panicularia nervata*).
Slender hair-grass (*Deschampsia elongata*).
Rush (*Juncus confusus*).
White foxtail (*Sitanion velutinum*).
Parry's-rush (*Juncus parryi*).
Rush (*Juncus mertensianus*).
Rush (*Juncus orthophyllus*).

Throughout the Hudsonian zone mountain bunch-grass (*Festuca viridula*) is by far the most abundant plant and the most desirable to revegetate. The relish with which several of the other species are grazed and their similar altitudinal range and abundance made it very difficult to determine which one ranks next in value, and the arrangement presented was not finally decided upon until after the third year's investigation.

Growth usually begins in the Hudsonian zone about the last week in June, and stock are given access to the lands early in July.

Arctic-Alpine Zone.—The Arctic-Alpine, or timberless, zone is not only unfavorable to tree growth, but to grazing plants as well. As shown in Plate XIV, figure 1, the zone is confined to the very highest crests and peaks, where the soil is shallow and poorly decomposed, the season of growth short, and nightly frosts common. Owing to the virtual lack of grazing in this region, it was not thought necessary to measure accurately the climatic factors.

The species of the Hudsonian zone are for the most part entirely absent in the Arctic-Alpine. Among the characteristic alpine plants are cat's-foot (*Eriogonum piperi*), whitlow-wort (*Draba aureola*), *Hoorebekia*

lyalli, hulsea (*Hulsea nana*), Alpine phacelia (*Phacelia alpina*), and false strawberry (*Sibbaldia procumbens*). Even these species occur sparingly.

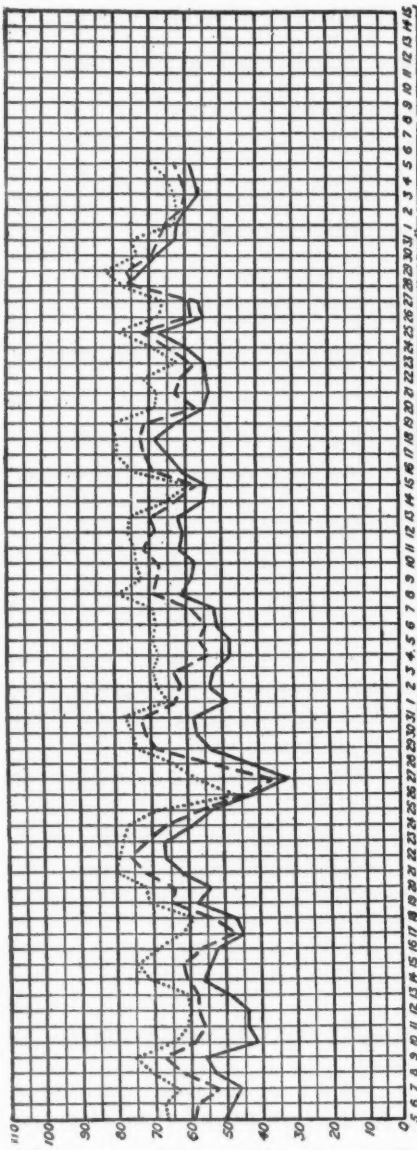

FIG. 1.—Curve showing the variation in the mean temperature in the Transition, Canadian, and Hudsonian grazing zones in 1909.

Growth does not usually begin until well into July and ceases about September 1. Naturally in this zone any species which succeeds in maturing viable seed must be vigorous and able to develop in a short time.

CLIMATE

Records of temperature, precipitation, and air humidity were kept in the Canadian, Transition, and Hudsonian zones during the main grazing season, in order to determine what differences in the season of growth they exhibit.

TEMPERATURE.—Figure 1 shows the mean temperatures of the respective zones derived from the daily maximum and minimum during the main growing season of 1909. While the mean temperatures in the three zones differed widely, there is a close relationship between the daily fluctuations. In all cases the mean is lower, usually by several degrees, in the Hudsonian zone than in the two lower ones, while the highest naturally comes in the Transition zone. The extremes from which the mean temperature was obtained show that

the variation in the maximum temperatures in the three zones is fully as great as in the case of the minimum. During the month of July, for example, the maximum temperature in the Hudsonian zone was 84°; in the Canadian, 90°; and in the Transition, 104° F. The highest temperature in the three zones during the entire growing season was 91°, 97°, and 105° F., respectively.

PRECIPITATION.—The higher temperatures characteristic of the less elevated lands are associated in the region of the study with a minimum precipitation. In the valley surrounding the Wallowa Mountains—that is, in the Transition zone—at an elevation of 3,600 feet, the annual precipitation is about 17 inches, the greater part coming in the spring, autumn, and winter. As a result, the vegetation often suffers for lack of moisture. In the Hudsonian zone, on the other hand, the larger amount of precipitation received is ample, and, with the exception of seedling plants, the vegetation is not affected by drought.

Figure 2 shows that the Transition and Canadian zones received 51.6 and 26 per cent less rainfall, respectively, than the Hudsonian. While

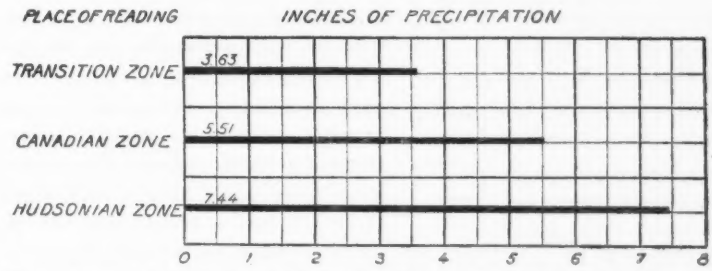

FIG. 2.—Diagram showing the total precipitation in the Transition, Canadian, and Hudsonian grazing zones during July, August, and September, 1909, inclusive.

the actual amount of precipitation during the growing season of 1909 was somewhat above normal, the ratio between the amount which fell in the different zones is similar to that of an average year. The greater amount of precipitation at the higher altitudes, together with the comparatively late date at which growth begins, accounts for the continuous development of the forage.

COMPARATIVE AIR HUMIDITY.—Since the Hudsonian zone has a relatively lower air temperature, a greater amount of precipitation, and a more humid soil than the lower zones, it would be natural to expect that the relative air humidity would be lower and transpiration less severe than in the lower areas. Figure 3, which gives the daily variations in air humidity derived from evaporation readings, shows this to be the case.

It was unexpectedly found that in the Hudsonian zone the evaporation was greater than in the Canadian zone immediately below. While the temperature and even the relative air humidity, as computed from psychrometer readings, were lower in the Hudsonian zone, the dense timber of the Canadian zone so interrupted the air currents as to materi-

ally diminish the evaporation there. In comparing the three zones, however, the evaporation in the Hudsonian and Canadian zones was found to be, respectively, 13 and 35.6 per cent less than that in the Transition zone. Owing to the relative great evaporation in the latter region, light showers, especially those which fall early in the day and are succeeded by a clear sky, are soon evaporated and so are of little value to plant growth. During a period of drought, other things being equal, a plant could not live nearly as long in the lower as in the higher elevations, on account of the excessive transpiration in the former locality.

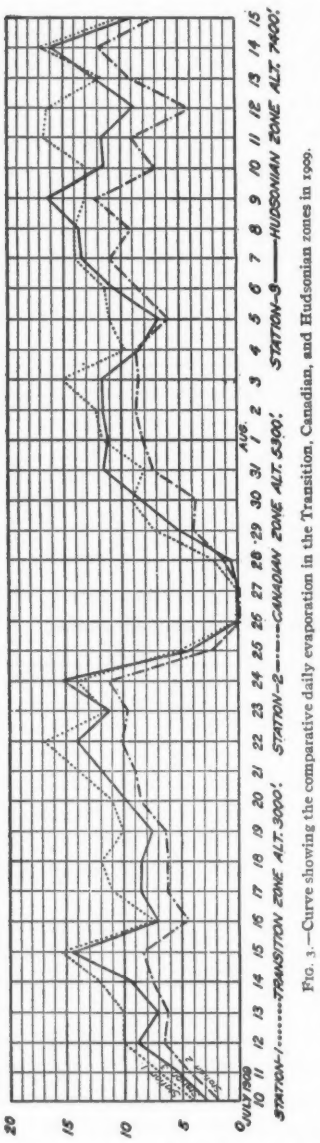

FIG. 3.—Curve showing the comparative daily evaporation in the Transition, Canadian, and Hudsonian zones in 1909.

To sum up the conditions peculiar to the Hudsonian zone as compared with the lower grazing type, the temperature is lower, the precipitation heavier, and the transpiration less. It is therefore easy to see that the relatively slow-growing and warmth-requiring vegetation in the lower lands could not thrive in the cooler and shorter growing season typical of the Hudsonian zone. Hence, only the most plastic and adaptable species of the Transition zone occur in the Hudsonian, and then only on the warmest and most exposed south slopes.

LIFE HISTORY OF THE FORAGE PLANTS

The growth requirements of range plants can best be determined by a study of individual species and the factors with which they have to contend from the time that they begin growth in the spring through the various stages of development to seed maturity, and then on to the permanent establishment and seed-bearing stage of the vegetation produced from seed of the original plants. The essential features of this almost double life cycle are: (1) Inception of growth, (2) flower-stalk

production, (3) development and maturity of seed, (4) viability of the seed crop, and (5) establishment of reproduction.

Owing to the relatively unfavorable conditions for plant growth and the demands made upon them for summer range, the high mountain lands are the ones most in need of revegetation. For this reason the life history of the forage plants and the factors affecting their activities were studied more intensively in the Hudsonian zone than elsewhere.

INCEPTION OF GROWTH

The time at which growth begins in the spring varies widely in the different zones. Thus, in the heart of the Hudsonian zone growth begins ordinarily about five weeks later than in the Canadian zone immediately below and seven weeks later than in the Transition zone. Even in the same zone the beginning of the growth period may vary by as much as 10 days from year to year, depending chiefly upon the climatic conditions during the spring, especially in May and June, but also to a certain extent upon the amount of snow accumulated during the winter. One year the early season may be characterized by warm, sunny days, and as a consequence the snow cover, especially on the more exposed situations, may disappear as early as June 20, though this is rather exceptional. In another year the snowfall in May and June may be as heavy as at any time during the winter. North and east exposures are always later in responding to growth than south and west aspects of the same elevation. Considerable difference exists also in the time when growth begins on different portions of the same slope.

The influence of local conditions on the inception of growth was well shown in the case of a north slope in the Hudsonian zone with an altitude at the crest of 7,850 feet and an incline of from 15° to 18°. With a succession of warm, sunny days the snow began to disappear first from the crest, then from the slope, and finally from the base. As the snow melted, growth began almost immediately. Before it had fairly begun on the slope, however, the crest showed a sparse covering of green, while a similar relation later existed between the slope and the base. In the early part of the season there was a marked difference between the amount of soil moisture at crest, slope, and base, the average percentages being 23.2, 27.6, and 39.9, respectively. As the season advanced, however, moisture conditions gradually became equalized, and in the latter part of the growing season the moisture content of the entire slope was practically uniform. For this reason, though growth began on the crest from three to six days earlier than upon the slope and from seven to nine days in advance of that on the base, toward the end of the growing period the vegetation as a whole presented a strikingly uniform appearance.

The period of growth resumption in each zone lasts ordinarily about 20 days. In the Hudsonian zone this period usually begins about June

25 and terminates about July 15. While climatic conditions have a direct influence upon the time when growth begins, the length of the growth-resumption period in a given locality is determined more by the vigor of the vegetation than by anything else. Where year after year the herbage has been removed prior to the time during which the nutrients necessary for spring growth are stored in the roots, growth begins several days later and vegetative development is strikingly less luxuriant than in the case of plants of the same species which have not been subjected to similar treatment.

FLOWER-STALK PRODUCTION

Under ideal conditions flower stalks begin to appear from 10 days to 2 weeks after growth has started. The stalks make a vigorous height growth, and there is a profusion of inflorescence, which is fertilized at an early date. Actually, however, the period of flower-stalk production is often retarded by cool temperatures and other climatic factors, so that the time the stalks begin to show may vary in different portions of the range as much as several days, similarly to the inception of growth. Obviously the two are closely related, an early and prolific herbage production being followed by an early and luxuriant flower-stalk development, and a late, scanty growth of herbage by a correspondingly late appearance of a few weak stalks.

The vigor of the vegetation and consequently the time and abundance of flower-stalk production are also strongly influenced by the way the lands are grazed. Close cropping, coupled with successive trampling prior to the full development of the plant, delays not only the flower-stalk production, but also the maturing of the seed crop in subsequent years. The period required for an overgrazed plant to regain its vigor depends on the amount of injury received and the situation in which it grows. Three seasons of protection from grazing are usually sufficient for herbaceous vegetation to recover its vigor fully.

To determine the actual difference in the time of flower-stalk production on closely grazed, moderately grazed, and protected areas, as well as the time required for overgrazed plants to recover their lost vigor, observations were made during three successive seasons of mountain bunch-grass areas grazed in different degrees, and on others completely protected from stock. The range selected was at an elevation of 7,300 feet in the heart of the Hudsonian zone. The unprotected or open range was grazed according to the usual practice, the forage crop being removed early in August each year, prior to maturity.

During the first year (1907) no difference was observed in the time of flower-stalk production on the protected and open ranges, since the vegetation on both had previously been weakened through grazing. In 1908 and 1909, however, there was a notable difference in flower-stalk production, as shown in Table I and Plate XV, figure 1.

TABLE I.—*Annual progression in the flower-stalk production on closed areas and open range*

Condition of range.	Period of flower-stalk production.			Estimated percentage of increase in flower stalks.		
	1907	1908	1909	1907	1908	1909
Closed to grazing....	July 10 to Aug. 20.	July 4 to Aug. 10.	July 1 to July 28.	0	20	60
Adjacent range open to grazing.	July 10 to Aug. 20.	July 8 to Aug. 20.	July 8 to Aug. 15.	.....	.....	.....

After the first year of protection mountain bunch-grass produced its flower stalks both earlier and more luxuriantly than on the adjacent range open to grazing. This was also true of other forage species. Though the advance in the time that the flower stalks appeared (4 and 7 days in 1908 and 1909, respectively) was not very great, the stalks were developed more uniformly, the total period required for the function on the protected area being 37 and 28 days in 1908 and 1909, respectively, and on the open area, 43 and 38 days.

To compare flower-stalk production on areas grazed in the usual way and on others protected from grazing until the seed crop can ripen, several small plots of mountain bunch-grass, 1 meter square, were clipped with shears just above the ground for three successive seasons. On half of the quadrats the herbage was clipped once each month, or three times during the growing season, while on the remaining plots cutting was not done until after seed maturity—about September 1. During the fourth and fifth seasons the herbage was undisturbed.

The results showed that in the case of the plots clipped monthly the vegetative growth decreased in abundance each successive season. In the fourth year the undisturbed herbage was exceedingly weak, short, and sparse. No flower stalks were produced until the vegetation had been given one full season of rest, and then only a few late weak stalks were sent up. On the plots clipped after seed maturity, however, the flower stalks were produced fully as early, as uniformly, and as profusely as in the case of the plants which had remained unmolested during the 5-year period. Herbage production was also equal to that on the protected areas.

On the open range, grazed early in the growing season, the flower stalks were produced at irregular periods, a few appearing early in July, the majority coming in August. On yearlong protected areas and on those protected until the seed crop had ripened, the stalks appeared early, practically all being in evidence before August 10.

Early and abundant production of flower stalks is of the utmost importance in seed production. Ordinarily from three to five weeks are

required for the proper development and "filling" of the seed after the flower stalks are produced. Climatic conditions usually become rather severe in the latter part of August, however, and flowers fertilized after the first week in August have not sufficient time to develop and mature their seed. Plants with low vitality are likely to produce flower stalks so late that the seed has no time to mature. A few species which reproduce vegetatively seem to have an inherent tendency toward irregular and late flower-stalk production, and such delay should not be confused with that due to low plant vigor. Of these species, pine-grass and yarrow, or wild tansy, require the longest time to produce flower stalks. On the lowest border of the Transition zone these species actually send up their flower stalks as early as July 10, and on the higher areas continue until inclement weather—about September 15—stops their activities.

PERIOD OF SEED MATURITY

Under the most favorable conditions the time required for the development of seed is about 25 days. The period varies slightly with the length of the growing season and is longest at the lower elevations. It also varies among different species, and the time given for ideal conditions should be considered as approximate.

Naturally the same factors which promote or retard the growth-resumption period and flower-stalk production also determine the time of seed maturity, though the last named fluctuates least, since toward the end of the growing season physical conditions, especially soil moisture and air and soil temperature, tend to become uniform throughout the range.

The length of the seed-maturing period varies widely from year to year as the result of the presence or absence of killing autumn frosts. In 1907 practically no seed of the more valuable perennial herbaceous species were matured in the Hudsonian zone until August 20, while in 1908 the ripening period came at least five days earlier. From this it might appear that the seeds were matured more slowly in 1908 than in 1907. This was not the case, however, the apparent difference being explained by the fact that in 1907 weather conditions after the first week in September were so unfavorable that the seeds which had not matured by that time were destroyed. In 1908, on the other hand, heavy frosts and low temperatures did not appear until September 20, and practically all the seed matured.

In 1908 seeds of mountain bunch-grass and other important species began to ripen on August 15, and by August 25 fully two-thirds of the crop had matured. After September 5 practically no immature seed were to be found, even on the cool north slopes at the higher altitudinal limits of the species. The secondary grazing plants, almost without exception, had matured their entire seed crop by September 10.

In 1909 the seed-maturity period began earlier than in the two preceding seasons. In the case of mountain bunch-grass and a few other species this difference amounted to as much as 10 days in the identical situations observed in previous years. As with the production of flower stalks, the latest period of seed maturity occurred in 1907. The seed of vegetation on the cool and moister north slopes invariably matured later than that on other exposures and on level land at the same altitude, the difference amounting to a week or 10 days. Elevation is, of course, influential in determining the time of seed maturity. Each increase of a thousand feet, other conditions remaining the same, brings about an approximate delay of a week. The chief factor in determining the time of seed maturity, however, as well as the size of the seed crop, is the vigor of the vegetation. Where the herbage had been grazed for several successive seasons when green and the vitality of the vegetation thus lowered, no seed was produced, or else the period of maturity came so late as to be seriously interfered with by frosts and low temperature. In contrast to this, the seed-ripening period on yearlong protected lands and on those not grazed until after seed maturity was much earlier and more uniform, while the amount of seed produced was notably greater.

On the unprotected range there was little difference in the time of seed maturity from year to year. On both the yearlong protected range and that grazed after seed maturity, however, the period came earlier each successive season, in direct ratio with the increase in vigor of the vegetation.

The importance of keeping the vegetation thoroughly vigorous is further exemplified by the clipping experiments. Where the herbage had been removed monthly for three successive seasons, no seed was developed in the fourth year when the plots remained undisturbed. On the other hand, on the plots clipped annually after seed maturity the seed crop was fully as large and matured at the same date as on lands from which stock were excluded.

The experiments show, therefore, that if the forage crop is left undisturbed until the seed has ripened, at which time the plants will have ceased growing, it will produce as large and as early a seed crop the following season as will vegetation on range not grazed at all. Clearly these facts are of the greatest importance in devising a system by which the forage may be grazed without interfering with seed production.

VIABILITY OF THE SEED CROP

The germinative power of the seed of the leading range plants was determined, in order to ascertain what reproduction might be expected under favorable conditions. In Table II, which gives the results of the tests, the high-range and low-range plants are grouped separately.

TABLE II.—*Average fertility of the seed of range plants from 1907 to 1909, inclusive*[a]

PLANTS OF THE HIGH RANGE

Name of plant.		Seed fertility (germination).
Common.	Scientific.	
		Per cent.
Mountain bunch-grass	Festuca viridula	12.2
Little bluegrass	Poa sandbergii	7.0
Short-awned brome-grass	Bromus marginatus	47.6
Tufted hair-grass	Deschampsia caespitosa	26.4
Onion grass, or mountain bluegrass	Melica bella	4.0
Reed-grass	Cinna latifolia	86.8
Alpine redtop	Agrostis rossae	36.0
Smooth wild rye	Elymus glaucus	21.2
Alpine timothy	Phleum alpinum	69.5
Western porcupine, or needle grass	Stipa occidentalis	27.0
White foxtail	Sutanion velutinum	69.5
Little needle grass	Stipa minor	29.8
Elk-grass	Carex geyeri	21.3
Tall swamp-grass	Carex exsiccata	15.2
Sheep sedge	Carex illota	27.5
Wire sedge	Carex hoodi	.....
Wood rush	Juncoides glabratum	7.5
Mountain onion	Allium validum	37.0
False hellebore	Veratum viride	24.0
Skunkweed, or Jacob's-ladder	Polemonium humile	42.0
Wild celery	Ligusticum oreganum	6.5
Blue beardtongue	Pentstemon procerus	18.5
Wild buckwheat	Polygonum phytolaccaefolium	9.5
Horsemint	Agastache urticifolia	22.2
Mountain dandelion	Agoseris glauca	36.0
Woolly weed	Hieracium cynoglossoides	10.9
Yarrow, or wild tansy	Achillea lanulosa	27.8
Coneflower	Rudbeckia occidentalis	21.8
Average germination		28.3

PLANTS OF THE LOW RANGE

Big bunch-grass	Agropyron spicatum	24.3
Pine-grass	Calamagrostis rubescens	69.6
Marsh pine-grass, or bluejoint	Calamagrostis canadensis	71.5
Mountain June-grass	Koeleria cristata	15.0
Slender hair-grass	Deschampsia elongata	41.6
Soft cheat	Bromus hordeaceus	48.2
Tall meadow-grass	Panicularia nervata	85.0
Geranium	Geranium viscosissimum	29.5
Fireweed	Chamaenerion angustifolium	21.5
Average germination		45.1

[a] In the case of a few species listed seed tests were made during two seasons only.

It will be observed that the viability of the seed of most plants is low. In the case of the important mountain bunch-grass, for example, barely more than one-tenth of the seed germinates. In a few cases mountain

bunch-grass seed showed a fair viability, the maximum germination obtained being 25.2 per cent, but the average of a great number of tests made under various degrees of temperature gave the figure in the table. In general, seed of the less desirable species, such as white foxtail and reed-grass, show a higher percentage of germination than that of mountain bunch-grass, short-awned brome-grass, and others. The germinative power of the seed was generally lowest in 1907, owing to the low vitality of the vegetation due to previous early grazing. In subsequent seasons on areas protected entirely from stock or until the seed had matured there was a pronounced increase in the germinative power of the seed.

It will be seen from Table II that, in general, seed fertility decreases with elevation, the average germination of the plants on the higher ranges being only 28 per cent, as against 45.1 per cent for those on the lower elevations. Even with the best conditions of growth and plant vigor, the vegetation of the region must struggle to mature its seed during a short and none too favorable growing season. The effect of exposure and of low vigor of the vegetation (as indicated by the date of maturity) on the germinative power of the seed is shown in Table III.

TABLE III.—*Effect of exposure and date of maturity upon germination of mountain bunch-grass*

Series No.	Source of seed.	Altitude.	Date of maturity.	Germination.
		Feet.		*Per cent.*
1	South exposure	7,400	Aug. 20	14.0
2	West exposure	7,400	Aug. 22	9.5
3	North exposure	7,300	Sept. 1	11.5
4	East exposure	7,350	...do....	11.0
5	South exposure	7,400	Aug. 31	7.0
6	West exposure	7,400	...do....	4.5
7	North exposure	7,300	Sept. 12	1.5
8	East exposure	7,350	Sept. 14	0

The data in this table bring out two important facts: (1) There is no difference in the vitality of the seed of mountain bunch-grass ripening before September 1, provided the variation in the maturing period does not exceed about 10 days. (2) There is a pronounced difference in the viability of seed which reaches maturity by September 1, as compared with seeds ripened September 10 or later, the latter showing practically no germinative power.

The same relationship between the germinative power of early and late-maturing seed was observed in the course of field sowing in the natural habitats, though in all such cases the germinative power of both classes of seed was higher.

The essential conclusions regarding seed germination are:

1. Even under the most favorable conditions the viability of the seed of practically all the forage species is low, especially on the high mountain lands.

2. Late resumption of growth in the spring and low plant vigor, both of which can be traced directly to premature grazing, result in a decrease in the amount of seed produced and in the germinative power of the seed itself.

3. If viable seed is to be produced, the vegetation must not be habitually deprived of its leafy foliage during the critical growing and food-storing period.

SCATTERING AND PLANTING OF THE SEED

But little time elapses between seed maturity and dissemination. This fact is highly advantageous, in that grazing may begin almost immediately after the seed matures without danger of having the crop consumed.

The distance the seed is carried from the parent plant depends chiefly upon the species and the wind. Grasses and grass-like plants, such as sedges and rushes, drop their seed near the parent plant. Those of plants like fireweed (*Epilobium* spp.) and *Crepis* spp., which are provided with bristly capillary hairs and pappus, and those of false hellebore, which are winged, are carried relatively great distances by the wind. Fireweed and dandelion do not grow in as dense stands as the grasses, but, as a rule, are more widely distributed over the range. About 90 per cent of the forage species depend primarily upon wind and water for the distribution of their seed. The remaining 10 per cent, of which huckleberry is an example, depend very largely upon animals for dispersal.

To insure reproduction of the forage plants, the seed must in some way get itself planted. Though nearly all seed will germinate on the surface of the ground where there is abundant moisture, the resulting seedling plants in a locality where the soil dries out early in the season are unable to extend their limited root systems deeply enough to reach the moist lower strata and consequently die from drought.

The size and character of the seed play an important part in the natural reproduction of range plants. The seed of some of the most important species, such as mountain bunch-grass, short-awned brome-grass, and wild celery, are large and light, and even though dropped promptly upon maturity in the autumn, months before germination takes place, are usually found uncovered on the ground in the spring. On the other hand, the seeds of wild onion and some of the sedges and rushes are smaller and heavier and have less difficulty in working into the soil. Among the valuable grasses observed, only one had become planted through natural means. This one exception was western porcupine grass, which is becoming securely established on the range not only in localities where it is abundant, but often on the tightly packed soils of denuded trails,

on hillside terraces formed by the trailing of sheep, and, in fact, everywhere that its seed is developed. In favorable situations 1 square meter of surface showed as many as 700 seedlings of porcupine grass in the spring of the year. This unusual aggressiveness is not due, as might be expected, to exceptionally strong seed habits, but chiefly to the morphology of the scale, or lemma, which closely envelops the seed. The scale is very rigid, with an awn about 1½ inches long protruding from the apex. At maturity this awn is tightly twisted, as shown in Plate XV, figure 2, but when moistened it untwists vigorously, causing the bent, needle-like point at the lower end of the scale to bore into the ground, the stiff, backward-turning hairs holding it in the earth when once started. The repeated twisting and untwisting of the awn with variation in the moisture finally results in the complete burial of the seed prior to the germination period.

Thus, if the seed of the valuable forage species is not planted by artificial stirring of the soil, undesirable species, such as white foxtail, may become established at the expense of the valuable range plants.

GROWTH AND ESTABLISHMENT OF REPRODUCTION OF FORAGE PLANTS

The production of a seed crop of high viability does not necessarily mean any material increase in the forage stand. The seedling plants are often seriously injured or destroyed in the fore part of the grazing season by low temperature and lack of soil moisture. Certain plants are not subject to as serious injury as others, and so the ultimate stand may consist of a single species. The growth and vitality of reproduction will be discussed under three heads: (1) "Development and loss of forage seedlings during first year;" (2) "Loss of forage seedlings during dormant period following first year;" and (3) "Growth and loss of forage seedlings during second and subsequent seasons."

DEVELOPMENT AND LOSS OF FORAGE SEEDLINGS DURING FIRST YEAR

During the first season of growth in the Hudsonian zone, approximately 10 weeks long, the seedlings do not grow tall enough to produce forage, though the young plants are sometimes cropped to a limited extent in the autumn. The height attained by mountain bunch-grass, as well as the root development, is shown in Plate XV, figure 3. It will be seen that the depth of the root slightly exceeds the height of that portion of the plant above ground. This plant represents about the average development of a forage seedling on well-drained and drier situations during the initial year of growth. On the lower elevations, owing to the longer growing season, the seedling plants usually attain much greater development than the one shown.

Observations extending over five successive seasons show that in normal years the low temperatures characteristic of the Hudsonian zone are responsible for considerable loss of seedlings during the first year of

growth. The extent of this influence is shown in figure 4. It will be observed that freezing temperatures occurred on three nights in July, 1909—namely, July 12, 17, and 27—the temperatures recorded being 30°, 23°, and 29° F., respectively. In August freezing temperatures occurred on the 1st, 4th, 20th, and 26th, the lowest being on the night of the 4th, when the temperature registered 28° F. Only on the nights of freezing temperature in July, however, was serious harm done, and then only to the young seedling plants. The greatest injury occurred on the more moist, but not marshy, situations, where the surface soil heaved as a result of alternate freezing and thawing. This action of the soil exposed portions of the roots of the seedlings, leaving them at the mercy of the sun and wind. In a few exceptional cases 50 per cent of the seedling stand was thus destroyed. The freezing temperatures during August were not destructive, since then the root systems were better developed and there was less heaving of the soil, on account of the lower moisture content of the surface layer.

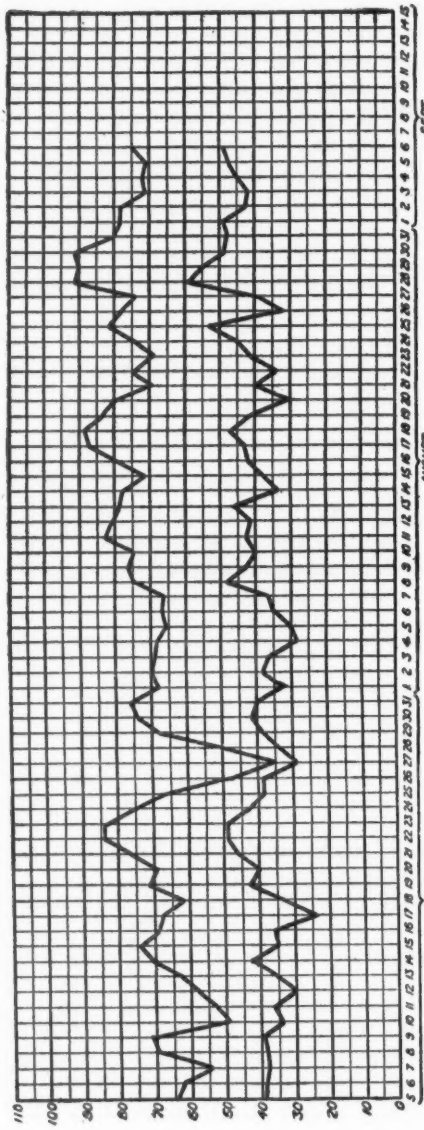

FIG. 4.—Curve showing the maximum and minimum temperature records in the Hudsonian zone (whitebark-pine association).

Because of the high elevation of the Hudsonian zone, the maximum temperature rarely exceeds 90° F. and, as a rule, does not seriously hamper the activities of the vegetation, though, in so far as it influences

the relative air humidity and increases transpiration and evaporation from the soil, it also decreases the available soil moisture.

With the limited amount of precipitation during the growing period in the region, the soil moisture gradually decreases as the season advances. Low temperatures and lack of moisture in the upper soil often work together to destroy seedlings, in that the seedling roots are first pushed up by the heaving of the soil during freezing to a point where there is not enough moisture available for growth.

The seedlings of no particular species seemed to suffer more seriously than any other in the same situation. Individuals which sprang from seed that had not found its way into the soil and which therefore had comparatively shallow root systems were, of course, the most seriously affected.

Plants of the same species growing in the same situation often exhibited contrasts in their ability to withstand drought, and when plants growing in different kinds of soil were observed, the contrast was great. This is shown in Table IV.

TABLE IV.—*Water content of soil at time of death of forage seedlings*

Name of plant, soil type, and situation.	Number of successive days of wilting.	Date of death.	Percentage of nonavailable water.	Average percentage of nonavailable water for each species.
Mountain bunch-grass:				
Basaltic clay loam—				
Quadrat station 4	8	July 22	6.8	.....
Seeded area	6	20	6.3	.....
Do	9	24	6.8	.....
Quadrat station 4, seedlings in flats	6	19	6.2	.....
Do	5	20	6.1	.....
Do	5	21	6.2	.....
Seeded area	10	23	7.2	6.51
Gravelly clay loam—				
Seeded area, seedlings in flats	4	19	5.4	.....
Do	5	19	5.7	.....
Do	3	20	5.4	.....
Do	6	.....	.....	.....
West slope	4	18	5.4	.....
Do	(?)	18	5.3	.....
South slope	5	19	5.4	.....
Do	4	18	5.6	.....
East slope	5	19	5.6	5.5
Western porcupine grass:				
Gravelly clay loam—				
West slope	6	21	5.2	.....
South slope	7	21	5.4	.....
East slope	6	21	5.2	5.26
Short-awned brome-grass:				
Gravelly clay loam—				
West slope	4	19	5.8	.....
South slope	3	19	5.6	.....
East slope	4	18	5.9	5.75

The figures in Table IV show two important facts: (1) In the finer soils a higher percentage of water is required to maintain the life of a seedling than in soils of coarser texture; and (2) mountain bunch-grass requires but little more available water than western porcupine grass, one of the deepest rooted species, to become established in a given soil. Mountain bunch-grass, moreover, will thrive on a soil containing less water than would be required for short-awned brome-grass. To judge from the nature of the situations invaded by mountain bunch-grass, the plant may safely be classed among the drought-resistant native species.

Numerous observations in 1909, supplemented by many counts on small unit areas in different range types and on different soils, showed that nearly the entire loss of seedlings occurred before August 1. After that date loss was prevented by cooler temperatures and by an increase in soil moisture resulting from precipitation. However, the loss before August 1 had been rather severe, varying from 20 to 70 per cent, according to the situation, with a general average of about 50 per cent.

In 1910 the seedling loss in the fore part of the season was approximately the same as in 1909, but the loss in the latter part was much greater, and only 25 per cent of the original stand remained vigorous and active in the autumn. This extensive loss was due to continued dry weather and high temperatures.

LOSS OF FORAGE SEEDLINGS DURING DORMANT PERIOD FOLLOWING FIRST YEAR

Table V shows that, in general, the loss of forage seedlings due to physical conditions from October 1, 1909, to July 1, 1910, approximately, was practically negligible. It will be seen that the heaviest seedling loss occurred on steep slopes, particularly on those where the soil was coarse and gravelly and the vegetation sparse. Quadrats 14 and 16 show this strikingly. The soil in quadrat 14, whose slope is 28.5° to the west, is very coarse and gravelly, and only one-tenth of the ground was covered with vegetation. In quadrat 16, with a slope of 3° to the south, the soil is mainly of clay loam, with a small amount of gravel, and three-tenths of the ground was covered with the same kind of vegetation as quadrat 14. The loss of seedlings on the two quadrats was 28.4 and 1.4 per cent, respectively. These losses were not due to severe temperatures, but primarily to heaving of the soil and erosion before growth began. Additional contrasts can be seen in quadrats 3 and 5, and 31 and 55.

TABLE V.—*Loss of forage seedlings during the dormant and winter period*

Number of each seedling species.	Quadrat No.	Slope and exposure.	Total number of vigorous seedlings remaining—		Loss.
			Autumn of 1909.	Spring of 1910.	
					Per cent.
80 Mountain bunch-grass	3	25° west	81	71	12.3
1 Western porcupine grass				.....	.....
244 Mountain bunch-grass	5	18° west	248	238	.....
4 Elk-grass				3	2.8
58 Mountain bunch-grass	13	16° west	59	55	7.0
1 Sickle sedge				0	.....
116 Mountain bunch-grass	14	28.5° west	116	83	28.4
61 Western porcupine grass	16	3° south	68	60	1.4
7 Yarrow				7	.....
116 Western porcupine grass	31	11° southeast.	138	92	26.3
17 Mountain bunch-grass				6	.....
30 Smooth wild rye	35	12° south	37	29	8.1
7 Western porcupine grass				5	.....
27 Smooth wild rye	38	4° southeast.	29	24	17.2
2 Little bluegrass				0	.....
138 Little bluegrass	42	11.5° south.	155	134	3.1
9 Smooth wild rye				8	.....
6 Yarrow				6	.....
2 Mountain bunch-grass				2	.....
128 Smooth wild rye	44	4° south	148	126	2.7
11 Yarrow				10	.....
9 Crepis (sp.?)				8	.....
91 Western porcupine grass	55	10° east	91	81	10.9

On steep hillsides where the original vegetation and network of roots had been seriously injured in the autumn by trampling, erosion carried the seedlings away or exposed portions of the more superficial (lateral) roots. Of the seedling loss during the resting period, 80 per cent was brought about in this way, though even this was nominal, averaging in the location studied only 7.3 per cent of the total stand.

Low temperatures were apparently responsible for the loss not directly due to gullying, but such loss was evident only in exposed situations. Practically all of the mountain lands are covered with a heavy blanket of snow before severe temperatures begin, which prevents excessive loss of water through the plant tissues aboveground and eliminates loss due to alternate freezing and thawing. No particular species appear to be especially immune to loss during the winter months. The roots of little bluegrass and sickle sedge seem to be exposed somewhat oftener than those of mountain bunch-grass, porcupine grass, short-awned bromegrass, and other species in the same situations. Mountain bunch-grass seedlings developed a rather unusually elaborate root system during the first year, which assisted in protecting them against adverse conditions.

GROWTH AND LOSS OF FORAGE SEEDLINGS DURING SECOND AND SUBSEQUENT SEASONS

During the second year nearly all species make vigorous growth, both above and below ground. Plate XVI shows the deep and spreading character of the roots of 2-year-old mountain bunch-grass (natural size) at the end of the second season. It will be seen that the roots are much longer than the leaf blades. The vertical roots reach well beyond the dry substratum during the most critical period of drought. The leaf blades, which number about 70 or 80 on the more vigorous individuals, are all basal, with an average length of about 4 inches, about half that of the deepest roots. This splendid root and herbage development provides the plant with abundant food-storage tissue, so that in the following season vigorous growth begins promptly.

During the third year the development of the plant is quite as marked as during the two preceding seasons (cf. Pls. XVI and XVII). Both roots and herbage grow rapidly from the first, though the growth of the former still greatly exceeds that of the leaf blades. Such development is essential, for the roots absorb moisture slowly, and where transpiration is great, nothing short of a well-developed root system can supply the plant with the moisture it requires. Owing to the depth and spread of the roots, the question of available soil moisture is not a serious one, since an ample supply exists 3 inches below the surface layer. At the start of the growing period there is a superabundant supply of moisture, and plants whose roots are well beneath the surface soil continue to extend them more deeply until the innumerable root hairs have worked themselves through the capillary spaces among the soil particles, thus insuring the plant against drought.

By the end of the third year mountain bunch-grass and other species complete their life cycles, and cease to be seedlings. Flower stalks and seed are then produced, as shown in Plate XVIII. At this time the plants are often as tall as older individuals. The specimen shown in Plate XVIII exhibits the maximum development attained, the average growth being shown in Plate XVII. The flower stalks (there are seldom more than three) of the 3-year-old plants as a rule are put forth a few days later than those of the parent or older plants. Consequently the seeds are not matured as early as are those of the longer established individuals, though the variation rarely exceeds five days. So extensive is the development of the plants by the second year of growth that the loss during that and subsequent seasons owing to climatic factors is negligible.

The facts derived from the study of the life history of the vegetation, which are important as a basis for a rational and practical grazing system, may be summarized as follows:

1. The flower stalks of the important grazing plants begin to appear about July 5 and are for the most part produced between that date and August 10. The more vigorous plants send up their flower stalks first. Plants weakened by annual close and early grazing do not produce flower stalks until late in the season, and then send up only a few.

2. The seeds begin to mature by August 15, and by September 1 the major part of the seed crop is ripened and disseminated. Plants weakened by close and early grazing do not mature seed unless the growing season is unusually long and exceptionally favorable.

3. The viability of the seed of most species is low. The germinative power varies with different species, but especially with the vigor of the plants. Those which make a weak vegetative growth produce seed of very low viability.

4. The seeds of the most valuable species lack means for working themselves into the ground, and, if reproduction is to be secured, they must be artificially covered.

5. In the Hudsonian zone the germination period begins about June 25, and growth begins generally by July 15.

6. During the first year of growth, a period of about 10 weeks, the forage seedlings make a vigorous development. Owing to the friability of the surface soil, however, and the superficial position of the roots at that time, there is rather a heavy loss of seedlings from freezing and drought during the spring period.

7. During the dormant periods there is virtually no loss of seedlings. The only factor causing loss is erosion.

8. In the second and subsequent seasons physical conditions are favorable to rapid development and growth of the young plants. By the end of the third season viable seed is produced.

DIFFERENT GRAZING SYSTEMS IN THEIR RELATION TO GROWTH REQUIREMENTS AND REVEGETATION

From the facts brought out by the life-history studies it is plain that a rational method of grazing should (1) avoid weakening the vegetation through continuous grazing prior to seed maturity; (2) utilize, so far as practicable, the trampling of the animals in planting the seed; and (3) provide for protecting the reproduction against heavy grazing until it is firmly established.

At the present time grazing on the National Forests is carried out under one of three more or less distinct systems: (1) Yearlong or season-long grazing year after year; (2) yearlong or season-long grazing combined with an occasional total restriction of stock during the entire year for the purpose of giving the forage plants a chance to reproduce; and (3) deferred grazing, which aims at a rotation in the time of using each portion of the range, each year allowing an area to reach seed maturity

before it is cropped, but grazing it after that period, in order to avoid loss of forage through nonuse and to assist reproduction by trampling in the seed.

In the following pages the comparative merits of the three grazing systems, from the standpoint of the requirements of the range plants for growth and reproduction, are discussed.

YEARLONG GRAZING

The term "grazing system" implies a definite plan of utilizing the forage crop in accordance with certain basic principles. Yearlong or season-long grazing, however, is characterized mainly by a lack of system, since it fails to provide for the removal of the herbage at any particular time in any locality. Its ultimate results to stock and the range are not considered.

It was this unrestricted grazing on National Forest lands prior to their inclusion that so seriously reduced the carrying capacity of the choice ranges. After the creation of the National Forests overstocking was eliminated as rapidly as the stockmen could meet the necessary reductions, and regular grazing seasons were established. Even under seasonal regulations, however, the prevailing practice of yearlong grazing has not been conducive to the most rapid improvement of the range. In northeastern Oregon sheep are permitted to enter the mountain grazing areas early in July, when mountain bunch-grass and most of the other palatable species begin to put forth their flower stalks. Up to August 1 the flower stalks are virtually as palatable as the leaf blades, and where the range is stocked to its full capacity, as it is in practically all cases, most of the stalks are removed prior to the formation of seed. Moreover, there is a tendency to graze the same lands prematurely each year, a practice which impairs herbage development. This not only prevents seed production, but also results in gradually decreasing the carrying capacity of the range through starvation of the forage plants. Prior to the time of seed maturity practically all of the range has been grazed over at least once, and, as a rule, only the vegetation on the inaccessible lands is allowed to mature seed.

After about August 1 the flower stalks are not eaten as a general rule, except in the case of certain moisture-loving species, such as butterweed (*Senecio triangularis*), but the vegetative portion, especially of the grasses, is so closely consumed as to prevent the manufacture of the food so essential to the development of the plants and the production of seed. Since the main seed-developing period in the Hudsonian zone comes in August, lack of an abundant food supply during the growth period is reflected in the low viability of the meager seed crop produced.

To determine which species are becoming established under the system of yearlong grazing, several typical areas, overgrazed in various degrees,

were studied in 1907 before the stock was turned on to them. Full notes were taken on about 300 plots, 1 meter square. The lands selected were of the open, parklike type, with a scattered growth of whitebark pine and occasional clumps of alpine fir. Mountain bunch-grass was the predominating herbage species. Certain portions of these ranges were seriously depleted, and the usual succession of early, aggressive annual weeds had replaced the original perennial type. At this altitude the annual plants are of little value for forage, though grazed to a limited extent in the spring when succulent and tender. On this account the annual plants are not included in Table VI, which gives the results of the two seasons' observations

TABLE VI.—*Seedling reproduction of perennial forage plants on mountain range areas in 1907 and 1908 under yearlong grazing*

1907

Date of observations.	Locality.	Slope and aspect.	Character of soil.	Percentage of moisture in soil.		Most characteristic species.	Percentage of ground covered by vegetation.	Number of unit areas counted.	Total number of seedlings.	Average number of seedlings per square meter.
				Minimum.	Average.					
August 5 and 6	Stanley Range (elevation, 7,400 to 7,600 ft.).	2° west	Gravelly clay loam	11.4	20.1	Little needle grass, Alpine redtop, and sickle sedge.	10	45	428	9.51
August 6 and 7	do	5° west	Light sandy loam	10.6	20.1	Mountain bunch-grass, onion grass, or mountain bluegrass, and short-awned brome-grass.	50	36	183	5.08
August 9 and 10	do	10° to 20° east	Clay loam	6.2	14.6	Elk-grass, sickle sedge, and short-awned brome-grass.	50	35	157	4.48
August 11	do	12° to 20° south	do	7.1	13.6	Elk-grass and short-awned brome-grass	40	10	16	1.60
August 13	do	5° north	Sandy clay loam	6.4	22.3	Mountain bunch-grass, Festuca ovina, and onion grass.	40	32	190	5.93
August 20	Sturgill Range (elevation, 7,700 to 7,800 ft.).	1° to 2° southwest	Deep sandy loam	23.4	30.2	Sickle sedge	(a)	25	674	26.96
August 20	do	5° south	Shallow, gravelly loam.	13.6	8.3	Mountain bunch-grass, little bluegrass, little needle grass, and Carex spp.	20	26	70	2.67
August 21	do	Level	Clay loam	7.1	8.2	Mountain bunch-grass, and big bunch-grass	20	10	1	.10
August 21	do	5° to 10° south	Gravelly clay loam.	10.3	6.5	Elk-grass and mountain bunch-grass	30	12	23	1.91
August 22	do	3° to 5° southwest	do	9.6	8.9	Mountain bunch-grass, onion grass, and elk-grass.	30	22	55	2.50
August 23	do	10° to 15° south	do	8.6	7.2	Elk-grass, and big bunch-grass	20	26	18	.69
August 23	do	5° to 10° east	Sandy, gravelly	10.1	.....	Mountain wheat-grass (*Agropyron violaceum*) and elk-grass.	20	18	10	.55

1908

July 20	Stanley Range (elevation, 7,400 to 7,600 ft.).	10° to 20° east	Clayey loam	10.8	17.3	Elk-grass, sickle sedge, and short-awned brome-grass.	60	16	69	4.3
July 20 and 21	do	1° west	Gravelly clay loam.	12.0	29.6	Alpine redtop, sickle sedge, and little needle grass.	12	22	286	13.0
July 22 and 23	do	5° west	Clay loam	5.9	24.0	Mountain bunch-grass, onion grass, and spiked trisetum.	20	26	130	5.0
July 25 and 27	do	15° to 20° east	do	8.6	19.3	Elk-grass, sickle sedge, and short-awned brome-grass.	50	14	74	5.3
July 27	do	5° southwest	do	9.2	26.4	Mountain bunch-grass, short-awned brome-grass, spiked trisetum, and onion grass.	15	24	170	7.1
July 28	Sturgill Range (elevation, 7,600 to 7,800 ft.).	1° to 2° southwest	Deep clay loam	21.2	34.7	Sickle sedge, yarrow, little needle grass, and western porcupine grass.	(b)	17	401	23.6
July 29 and 30	do	3.6° southwest	Clay loam	9.0	22.0	Mountain bunch-grass, big bunch-grass, and little bluegrass.	40	12	50	4.2
July 31	do	5° south	Gravelly clay loam.	5.4	16.1	Little needle grass and big bunch-grass	20	14	49	3.5
August 3	do	Level	do	8.5	17.8	Little bluegrass and little needle grass	10	9	36	4.0
August 4 and 5	do	4° to 7° south	Clayey loam	9.3	11.8	Mountain bunch-grass, elk-grass, smooth wild rye, and horsemint.	25	11	36	3.3
August 8 and 9	do	5° east	Gravelly clay loam.	11.0	18.0	Mountain bunch-grass, onion grass, and little bluegrass.	40	12	76	6.4
August 10	do	Level	do	8.2	14.8	Big bunch-grass, western porcupine grass, and sickle sedge.	35	14	57.4	4.1
August 13	do	2° south	Black loam	16.4	28.2	Elk-grass, sickle sedge, slender hair-grass, and tufted hair-grass.	60	10	113	11.3

[a] Denuded.

[b] Almost denuded.

The data given in Table VI, supplemented by observations made in 1908 and 1909, show conclusively that on the typical lands studied the important perennial forage species are not being reestablished. For example, such important species as mountain bunch-grass, little blue-grass, and big bunch-grass gave a maximum count of 6.4 seedlings per square meter, as opposed to one of 26.96 for sickle sedge, a species of little value. Even on the lands which still support a fair stand of the original valuable forage virtually no reproduction is taking place. Mountain bunch-grass, which produces flower stalks at a relatively early date, and whose chances are therefore good for maturing a viable seed crop, shows no reproduction from seed where the ranges are grazed each year before the first week in August.

Practically all the seedlings on these ranges are of inferior species. Sickle sedge, an unpalatable but aggressive perennial, forms not less than nine-tenths of the total perennial seedling stand. This sedge matures a strong seed crop at a relatively early date and, in addition, perpetuates itself abundantly by offshoots from the rootstocks, which later develop seed. Besides sickle sedge, there was an occasional seedling of western porcupine grass, little needle grass, short-awned brome-grass, and slender hair-grass. The first three species are fairly good range plants, but the last named is grazed only to a limited extent early in the season. Probably because of this fact slender-hair-grass seedlings were more in evidence than any of the others.

The maximum seedling density occurred on old bed grounds, where the vegetative cover was exceedingly scarce. The average number of seedlings obtained per square meter for all counts made upon such lands was 26.96 and 23.6 in 1907 and 1908, respectively. This exceeds by about 50 per cent the seedling stand for any other type of range examined. There are three chief reasons why the seedling stand is dense on bed grounds: (1) The unpalatability of the parent species, coupled with early maturity of the seed; (2) thoroughness with which the seed is planted; and (3) relatively high water content of the soil.

The seed of sickle sedge usually matures and drops before August 1, and in consequence the plant is neither weakened nor the seed production interfered with by foraging animals. Though on most bed grounds the soil is hard-packed, on the particular ones examined it was loose and porous, and the trampling assisted in conserving its moisture by pulverizing the surface. During the main growing season in 1907 and 1908 the soil moisture content of the bed ground averaged 30.2 per cent, exceeding by 7.9 per cent that of any other locality studied, except the swales.

To sum up, it may be said that season-long grazing continued year after year seriously interferes with the growth of the vegetation, decreasing both the quantity and palatability of the forage crop. By the

failure of the forage plants to produce seed, reproduction is prevented, resulting in a gradual decline in the carrying capacity of the lands. Even under conservative use the carrying capacity of the range does not improve rapidly through reproduction of the more desirable species.

YEARLONG PROTECTION

To determine the practicability of reseeding the range through yearlong protection from grazing, five typical overgrazed areas, situated at various elevations from 3,000 to 7,500 feet, were selected for study. Each area was fenced in 1907, and observations were made during four successive seasons. The results from the areas in each zone are presented separately.

HUDSONIAN ZONE.—The areas closed to stock in the Hudsonian zone had been subjected to close yearlong grazing for several seasons (Pl. XXI, figs. 2 and 3), and because of the resultant low vitality of the vegetation practically no seed was produced during the first two seasons. In the third and subsequent seasons, however, a satisfactory seed crop of average viability was produced. The vegetative changes which took place in representative quadrats are shown in text figures 5 and 6.

It will be seen that at the time of their establishment the quadrats contained no perennial forage seedlings. The first year passed without any making their appearance. In 1909, however, 7 seedlings appeared after the germination period, but, as shown in figure 6, only 5 survived the subsequent dry season. On the denuded quadrat (fig. 6, quadrat 2) 2 mountain-bunch-grass seedlings came in during 1908, both of which succumbed later. In 1909, 10 seedlings were found in the spring, only 6 of which survived the season. Seed was produced in abundance each year, but for the most part remained on the surface of the soil. At the beginning of the study the quadrats were stocked with an inconspicuous and useless plant called knotweed (*Polygonum ramosissimum*), which is common on overgrazed ranges throughout the mountain-bunch-grass association. On the permanent quadrats this species no more than held its own, but on the denuded plots it increased prodigiously.

The contrast in the aggressiveness of reproduction of the annual and perennial species on protected areas, as shown in the case of mountain bunch-grass and knotweed, holds generally. The only perennial species which reproduced well under yearlong protection was western porcupine grass, the seed of which, as already pointed out, is planted by means of an awn attached to the floral glume.

The fact that practically no reproduction from seed was secured as a result of yearlong protection does not necessarily mean that such protection will not bring about an increase in the carrying capacity of the range. As a matter of fact the carrying capacity was increased through the production by the original perennial plants of more and longer leaf

blades and by an increase in the size of existing tufts or hummocks of tussock-forming plants. The leaf-blade increment is shown in Plate XXI, figures 2 and 3, where contiguous areas protected and grazed annually

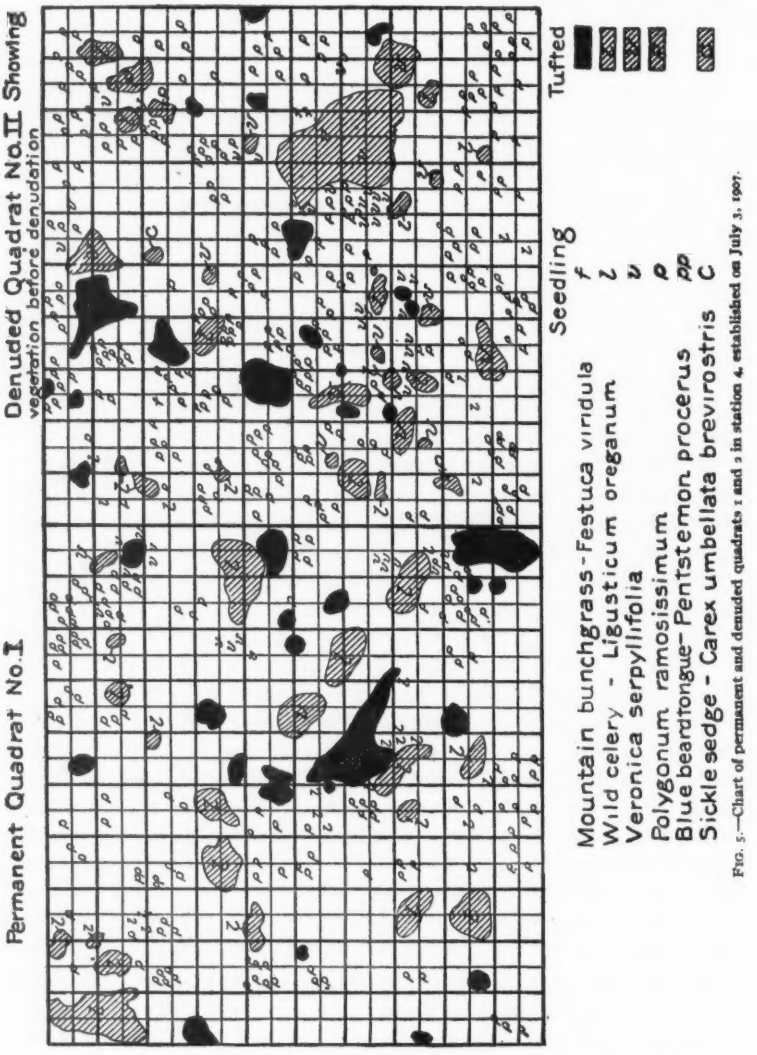

FIG. 5.—Chart of permanent and denuded quadrats 1 and 2 in station 4, established on July 3, 1907.

prior to seed maturity are compared. The leaf blades began to increase in number and length after the first year of protection and continued throughout the four years. The greatest development in the foliage came in the second year of protection, when the plant for the first time

was able to manufacture ample food. Many species of grass had doubled in length by the end of the fourth year.

The increase in actual stand or ground cover was due almost entirely to the enlargement of the tufts, and text figures 5 and 6 show that even under season-long protection the bunch-grasses and other valuable plants

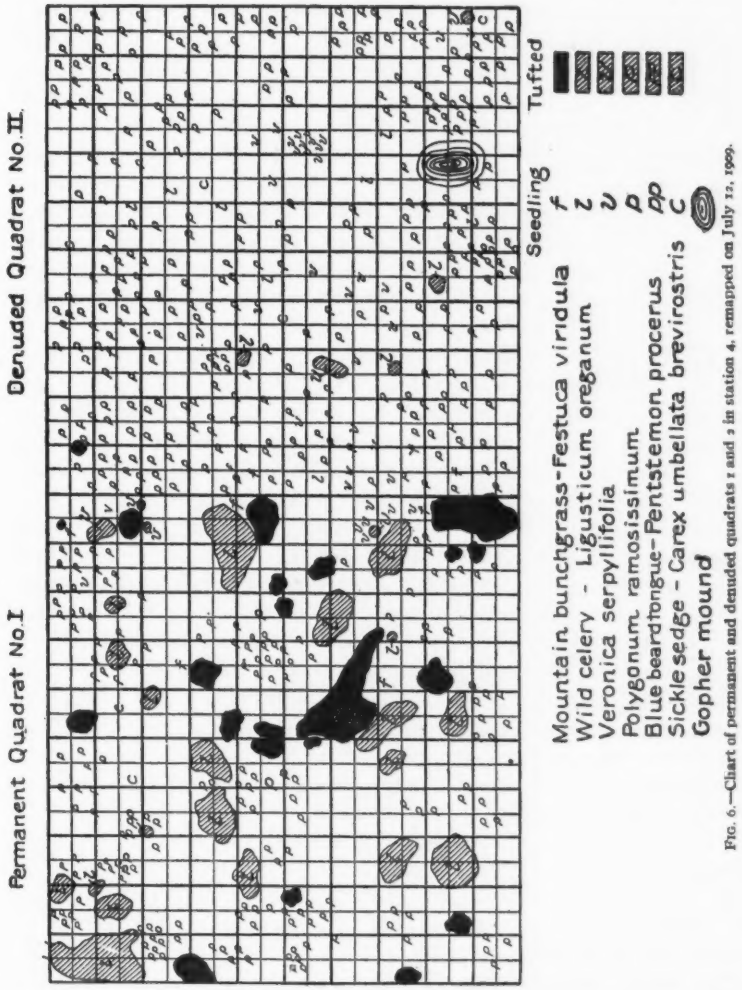

FIG. 6.—Chart of permanent and denuded quadrats 1 and 2 in station 4, remapped on July 12, 1909.

do not increase rapidly by this means. Planimeter measurements of the tufts showed an average increase in diameter of only 18 per cent for the third year of complete protection.

The young, small tufts were the only ones to increase noticeably in size. The tufts of mountain bunch-grass and most tussock-forming

species seldom measure more than 12 inches in diameter, and with the approach toward full development the annual increase becomes less and less. At just what age the hummock or tuft reaches full development is not definitely known, the age doubtless depending upon the species and situation.

TRANSITION ZONE.—Areas were carefully selected and fenced for study in the Transition zone in July, 1907. The range studied had been so seriously depleted that it was difficult to ascertain exactly what plant species constituted the main forage crop. The grasses found in more or less abundance at the time the plats were established were soft cheat, slender hair-grass, Olney's bluegrass, mountain June-grass, pine-grass, big bunch-grass, and western porcupine grass. Other important forage plants occurring sparingly were yarrow, alfileria (*Erodium cicutarium*), arnica (*Arnica cordifolia*), and geranium. Though the ground appeared to be nearly denuded, there was here and there a somewhat conspicuous stand of *Erigeron aureus*, stonecrop (*Sedum douglasii*), *Clarkia pulchella*, and Douglas knotweed (*Polygonum douglasii*).

During the first year of protection there was practically no plant invasion of the permanent quadrats (Pl. XX, fig. 3), but when the fall rains came—about September 1—the early stages of invasion became apparent on denuded areas. The plants to enter first were knotweed, an inconspicuous annual weed, *Clarkia pulchella*, *Erigeron aureus*, alfileria, soft cheat, western porcupine grass, and slender hair-grass, named in the order of their abundance. In the second year practically the same species entered the quadrats, with the addition of a mixed association of three perennial grasses—mountain June-grass, big bunch-grass, and pine-grass. Geranium, arnica, and stonecrop were also noted. At this time soft cheat, an annual species, was the most conspicuous and aggressive.

By the end of the third year, 1909, soft cheat had made such a rank growth that in certain portions of the protected area it had completely replaced the shorter annual weeds (cf. Pls. XX, fig. 3, and XXI, fig. 1). In the denuded quadrats certain perennial species, mountain June-grass, big bunch-grass, Olney's bluegrass, geranium, and yarrow, had also begun to appear as forerunners in the permanent establishment of perennial species. As a result of protection from grazing, the carrying capacity of the protected area as a whole had increased 150 per cent (Pl. XXII). This figure represents the increment in the ground cover within the quadrats rather than the weight of the forage produced. Fully four-fifths of the new growth was composed of annuals, with soft cheat easily predominating. Seeds of this species are small and, like those of western porcupine grass, work their way into the ground by means of special contrivances. The larger and lighter seeds of the perennial plants were found on the surface of the ground at the time of germination, and in consequence practically no seedlings of these species had been established. The perennial species had reproduced vegetatively, but the increase was by no means rapid.

On both the lower and more elevated lands the new forage resulting from yearlong protection consisted almost exclusively of annuals. A very small percentage indeed of the new stand was established through the reproduction of perennial plants. During the first two seasons of protection, even at the lower elevations, the perennials produced practically no fertile seed. In the third season viable seed were produced. The perennial vegetation, which previous to protection from grazing made such a weak growth that its presence was not observed, finally became conspicuous after one or two seasons of rest. Even under the most favorable conditions reproduction by the perennial species is slow, since the seeds are large and unable to work themselves beneath the surface of the soil. The nonuse of the forage under yearlong protection is a serious matter and would have to be considered before this system could be pronounced practicable. Moreover, the accumulation of inflammable material during the period of protection would result in increased fire danger. Under any circumstances it could not be carried out on a large scale without a radical readjustment of the stock industry.

To sum up the facts regarding yearlong protection: The system is not an efficient one, because the most valuable perennial species fail to reproduce by seed. While the carrying capacity of the land is increased, this increase is slow and does not compensate for the waste of the forage crop during the long period necessary for revegetation.

DEFERRED GRAZING

Unlike the two grazing systems just discussed, deferred grazing is based upon the requirements of the vegetation through practically a double life cycle, as defined in the section on the life history of the range plants.

To determine the effect of the deferred grazing system, the vegetation in the different grazing zones was studied for two successive seasons. Convenient areas which had been overgrazed in various degrees and which were large enough to support a band of sheep after the seed had ripened were closed to grazing from the beginning of the season until the seeds of the important species had matured. Upon maturity of the seed crop the range was grazed moderately by a band of sheep during the remainder of the season. The following year the same area was closed to sheep for the same period in order to give the seedlings an opportunity to develop a root system strong enough to withstand trampling and also to permit a second seed crop to be developed and disseminated in case the first year's seeding was unsuccessful. When the area had been satisfactorily reseeded, it was grazed early in the season, and a second area, large enough to maintain a band of sheep from the time of seed maturity to the end of the season, was reserved for deferred grazing. Results of a study to determine the abundance of seedling reproduction under the deferred grazing system, as compared with that under other systems, are shown in Table VII.

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TABLE VII.—*Comparative seedling reproduction of perennial forage plants on similar areas under yearlong grazing and deferred grazing—Hudsonian zone*

Character of original vegetation.[a]	Percentage of ground covered by original vegetation.	Character of soil.	Slope and aspect.	Reproduction.					
				Yearlong grazing (1908).			Deferred grazing (1909).		
				Number of unit areas counted.	Total number of seedlings.	Average number of seedlings per square meter.	Number of unit areas counted.	Total number of seedlings.	Average number of seedlings per square meter.
Sickle sedge, yarrow, little needle grass, and western porcupine grass	(b)	Deep clay loam	1° to 2° southwest	17	401	23.6	9	261	29.0
Mountain bunch-grass, big bunch-grass, and little bluegrass	40	Clay loam	3.6° southwest	12	50	4.2	7	220	31.5
Little needle grass and big bunch-grass	20	Gravelly clay loam	5° south	14	49	3.5	10	503	50.3
Little bluegrass and little needle grass	10	do	Level	9	36	4.0	8	337	42.1
Mountain bunch-grass, elk-grass, smooth wild rye, and horsemint	25	Clayey loam	4° to 7° south	11	36	3.3	9	549	61.0
Mountain bunch-grass, onion grass, and little bluegrass	40	Gravelly clay loam	5° east	12	76	6.4	8	386	48.1
Big bunch-grass, western porcupine grass, and sickle sedge	35	do	Level	14	57	4.1	10	219	21.9
Elk-grass, sickle sedge, slender hair-grass, and tufted hair-grass	60	Black loam	2° south	10	113	11.3	6	170	28.3
Average				12.4	101	7.5	8.4	330.6	39.0

[a] Named in the order of its abundance.

[b] Almost denuded.

SEEDLING REPRODUCTION SECURED

It will be seen that as a result of the deferred system of grazing the density of forage seedlings was from 2 to 10 times as great in 1909 as in 1908. Quite as important as the density was the identity of the seedling species. It will be recalled that where yearlong grazing was carried on, seedlings, aside from the annual weeds, consisted of two early-maturing annual plants, sickle sedge and slender hair-grass, together with a more valuable species, western porcupine grass. On the yearlong protected plots practically the only species were the few with small, heavy seeds, and the two porcupine grasses (*Stipa minor* and *S. occidentalis*) which are self-planting. Table VII shows that where deferred grazing was carried out the ground became stocked with seedling plants of all species which produce seed. The most valuable species, mountain bunch-grass, which failed completely under yearlong grazing and yearlong protection, responded exceptionally well. Its seedlings were found in all situations where there were parent plants to produce the necessary seed crop.

In the Canadian zone several of the valuable species which failed to reproduce under either of the other systems regenerated more or less abundantly under deferred grazing.

Although, under deferred grazing, forage seedlings were found wherever there were enough parent plants to produce the necessary seed, the proportion of the seedling stand which ultimately became established depended mainly upon the habitat and climatic conditions, as well as upon sufficient protection from grazing during the period of establishment.

LOSS OF SEEDLING REPRODUCTION BY GRAZING

To determine the extent to which moderate deferred grazing reduces the stand of valuable forage seedlings and whether the subsequent seedling stand resulting from the additional seed crop when thoroughly planted by trampling will offset the number of seedlings lost through grazing, observations were made on selected plots at medium and high elevations. The first observations recorded the character of the vegetation in and around each quadrat for a radius of 10 feet; the density of the herbaceous vegetation within and without the quadrat; the character of the soil and the slope and exposure; and the total number and identity of the seedlings within the quadrat, and their health vigor at the time of observation. With such data it was possible to account for any unusual loss resulting from subsequent grazing. It was recognized, for example, that a seedling, even when deeply rooted, is much more likely to be destroyed by trampling if it is situated on an abrupt hillside, especially in a denuded gravelly soil, than if situated in a level glade between tufts of grass with intertwining roots. Again, a seedling growing under adverse moisture conditions does not develop as elaborate and deep a root system as one which has received enough moisture to furnish the neces-

sary nutrients and so can not withstand as much disturbance of the soil. After the lands had been grazed and sufficient time had been allowed for the vegetation to recover, each quadrat was again observed and notes taken on the total number and identity of the forage seedlings which remained, the number of seedlings found dead, the number unaccounted for, the number whose recovery was doubtful, and the condition of the remaining seedlings at the time of the recounts.

AT MEDIUM ELEVATIONS.—The entire area studied slopes to the west and has a minimum altitude of 5,500 feet and a maximum which brings it into the lower Hudsonian zone. The topography is so irregular and there is so much down timber that the herbage can be grazed only under the most skillful open herding. The lower portion of the range is of the browse type, the much relished Nuttall willow predominating. The undergrowth consists of a host of weedy species, such as fireweed and its associates, with a scattering of smooth wild rye and short-awned brome-grass (Pl. XXIII). At the highest limits of Nuttall willow, seedlings of these species, on account of the shorter growing season, were not developed to the same extent as at the lower altitudes.

The forage stand in existence before and after grazing is shown in Tables VIII and IX.

TABLE VIII.—*Record of native forage seedling stand at medium elevation during the first week in August, preceding grazing*

Quadrat No.[a]	Character of vegetation in and around quadrat within radius of 10 feet.[b]	Density of vegetation.[c]		Character of soil.	Slope and exposure.	Total number of seedlings in quadrat.	Number of plants of each seedling species.	Condition of seedlings at time of observations.
		Within quadrat.	Without quadrat.					
1.....	Smooth wild rye and mountain bunch-grass.	1/10	2/10	Gravelly clay loam....	16° west [d].....	155	142 smooth wild rye..... 13 mountain bunch-grass.....	Good, though a few had died previously.
2.....	Yarrow, smooth wild rye, valerian, and false hellebore.	2/10	3/10	Clayey loam.....	20° west.....	201	193 Smooth wild rye..... 7 Sickle sedge.....	Soil dry, seedlings indicating lack of water..
3.....	Smooth wild rye, skunkweed, valerian, and sickle sedge.	1/10	2/10	.....do.....	24° west.....	43	1 Elk-grass..... 35 Smooth wild rye..... 1 Sickle sedge..... 1 Mountain bunch-grass.....	Many seedlings found dead, remaining ones showing lack of water.
4.....	Smooth wild rye, mountain bunch-grass, and valerian.	2/10	2/10	.....do.....	18° west.....	125	105 Smooth wild rye..... 14 Mountain bunch-grass..... 6 Sedges.....	Fair condition.[e]
5.....	Mountain bunch-grass, smooth wild rye, and lupine.	2/10	5/10	Deep clay loam.....	18° west.....	61	52 Smooth wild rye..... 9 Mountain bunch-grass.....	Good.
6.....	Smooth wild rye, lupine, mountain June-grass, valerian, and sickle sedge.	4/10	4/10	.....do.....	15° west.....	93	83 Smooth wild rye..... 6 Sickle sedge..... 4 Mountain bunch-grass.....	Do.
7.....	Short-awned brome-grass, smooth wild rye, and false hellebore.	5/10	5/10	Shallow, gravelly clay.	12° west.....	112	91 Short-awned brome-grass..... 19 Smooth wild rye..... 2 Sickle sedge.....	Do.
8.....	Short-awned brome-grass, mountain June-grass, and skunkweed.	4/10	4/10	Clay loam heavily impregnated with decaying wood.	12° west.....	80	64 Short-awned brome-grass..... 16 Smooth wild rye.....	Do.[e]
9.....	Smooth wild rye and valerian.....	1/10	4/10	Gravelly loam.....	20° southwest.	54	51 Smooth wild rye..... 1 Sickle sedge..... 1 Mountain bunch-grass..... 1 Elk-grass.....	Suffering from drought.
10....	Smooth wild rye, elk-grass, and false hellebore.	1/10	1/10	.....do.....	18° west.....	60	53 Smooth wild rye..... 6 Elk-grass..... 1 Sickle sedge.....	Good.
11....	Smooth wild rye, valerian, and yarrow.	6/10	5/10	Clay loam.....	22° west.....	94	89 Smooth wild rye..... 5 Sickle sedge.....	Seedlings wilting, tips of leaf blades dead.
12....	Smooth wild rye, false hellebore, and yarrow.	1/10	2/10	Slightly granitic clay loam.	26° west.....	66	58 Smooth wild rye..... 6 Sickle sedge..... 1 Mountain bunch-grass..... 1 Elk-grass.....	Do.

[a] These quadrats were remapped subsequent to grazing, the results of which appear in Table IX.
[b] Only the most predominant species are recorded under this heading. The species are arranged in the order of their abundance, the most predominant being given first.
[c] To represent the density of growth 10 is taken as complete ground cover.
[d] Situated on old sheep path.
[e] Gullying of the soil exposed the roots of a few seedlings.

TABLE VIII.—*Record of native forage seedling stand at medium elevation during the first week in August, preceding grazing*—Continued

Quadrat No.	Character of vegetation in and around quadrat within radius of 10 feet.	Density of vegetation.		Character of soil.	Slope and exposure.	Total number of seedlings in quadrat.	Number of plants of each seedling species.	Condition of seedlings at time of observations.
		Within quadrat.	Without quadrat.					
13....	Smooth wild rye and short-awned brome-grass.	2/10	4/10	Black clay loam.....	16° west.....	199	178 Smooth wild rye..... 19 Short-awned brome-grass..... 2 Sickle sedge.....	Fair, competition between rye-grass seedlings somewhat severe.
14....	Smooth wild rye, western porcupine grass, lupine, and valerian.	5/10	1/10	.....do.....	15° west.....	45	42 Smooth wild rye..... 3 Western porcupine grass.....	Good.
15....	Smooth wild rye and false hellebore...	5/10	3/10	Deep clay loam.....	13° west [a].....	105	101 Smooth wild rye..... 4 Short-awned brome-grass.....	Do.
	Average.....	.....	.....	.....	.....	100.8		

[a] Situated on old sheep path.

TABLE IX.—*Record of native forage seedling stand at medium elevation during the first week in September, after grazing*

Quadrat No.	Total number of seedlings remaining.	Total loss.	Percentage lost.	Number actually found dead.	Number not accounted for.	Number of plants of remaining seedling species.	Total number whose recovery is doubtful.[a]	Condition of remaining seedling stand at time of recount.	Remarks.
1	66	73	47.1	7	60	62 Smooth wild rye 4 Mountain bunch-grass	3	All native forage eaten closely in quadrat, leaving many roots exposed.	
2	98	103	51.2	11	90	92 Smooth wild rye 4 Sickle sedge 2 Elk grass	2	Sheep trail through part of quadrat, destroying and weakening many seedlings.	Sheep trail a foot wide and 4 inches deep.
3	12	31	72.1	3	27	10 Smooth wild rye 1 Sickle sedge 1 Mountain bunch-grass	1	Forage closely grazed and trampled	All vegetation eaten into the ground.
4	54	71	56.8	8	60	44 Smooth wild rye 6 Mountain bunch-grass 4 Sedge	3	Trail through quadrat destroyed and weakened all seedlings in its path.	Many roots of seedlings exposed, due to soil washing.
5	28	33	54.1	5	27	26 Smooth wild rye 2 Mountain bunch-grass	1	Moderately grazed; seedlings in good condition.	
6	30	63	67.7	13	49	26 Smooth wild rye 4 Sickle sedge	1	Badly trampled; many seedling roots exposed.	
7	67	45	40.2	11	31	61 Short-awned brome-grass 6 Smooth wild rye	3	Closely grazed, but seedlings in good condition.	
8	74	7	8.6	4	0	68 Short-awned brome-grass 6 Smooth wild rye	3	Grazed very moderately; seedlings not injured.	Quadrat not in open, exposed position.
9	31	23	42.6	3	15	29 Smooth wild rye 1 Mountain bunch-grass 1 Elk grass	5	Grazed closely; seedlings in fair condition.	
10	31	29	48.3	3	22	28 Smooth wild rye 3 Elk grass	4	Moderately grazed; seedlings vigorous.	
11	46	48	51.0	7	39	44 Smooth wild rye 2 Sickle sedge	2	Very closely grazed and badly trampled; seedlings rather weak.	On open grazing land.
12	29	37	56.0	6	25	28 Smooth wild rye 1 Sickle sedge	6	Moderately grazed; seedlings vigorous.	
13	77	121	61.1	15	106	75 Smooth wild rye 2 Short-awned brome-grass	0	do	
14	22	23	51.1	3	12	19 Smooth wild rye 2 Short-awned brome-grass 1 Mountain bunch-grass	8	Badly trailed and trampled; seedlings fairly strong.	No seedlings left in trail.
15	47	58	55.2	12	40	46 Smooth wild rye 1 Short-awned brome-grass	6	do	Do.
Average.	48.5	50	50.9						

[a] Of the seedlings whose recovery from grazing or drought was doubtful, none were included in the number composing the "total number of seedlings remaining," as shown in column 2 of this table.

In Table VIII it will be seen that the seedling stand before grazing was rather dense, the average for all quadrats being 100.8 per square meter. Fortunately the less valuable species, such as sickle sedge, were the ones most weakened by drought, their condition, as will be noted, corresponding closely with the character of the soil, the more porous types supporting the less vigorous plants.

After grazing (Table IX) the average stand was reduced to 48.5 per square meter, a loss of 50.9 per cent. The heaviest loss was at the upper limit of the area, where the short growing season caused the seedlings to be less deeply rooted. At the lower elevations the heaviest loss was where the young plants were cropped. Many of the lateral roots were pulled out or broken, and death followed.

On account of the rather severe and uneven grazing, it was practically impossible to determine definitely what species were best able to withstand trampling. An examination of the root systems showed that smooth wild rye had almost invariably pushed its roots more deeply into the soil than any other species. Short-awned brome-grass also develops an unusually strong, deep, and spreading root, and showed ability to withstand trampling and to recover its vigor when portions of the root were pruned off below the surface, or even when segments of the rootlets were exposed to the air. Seedlings of mountain bunch-grass also withstood trampling comparatively well, notwithstanding the fact that at the time the range was cropped it was not so far advanced as the other species.

At High Elevation.—Owing to a great variety of conditions at the high elevations, 62 quadrats were established late in August before grazing. The range, which has a minimum altitude of approximately 7,500 feet, is distinctly herbaceous, the growth consisting primarily of grasses, with mountain bunch-grass and western porcupine grass predominating in the order named. (See text fig. 5.) In addition, there are several species of sedges and rushes, with a sprinkling of weeds and non-grasslike plants, especially in the moister situations.

At the time of the first observations nearly all the seedlings were in good condition, though dead individuals were often found in the drier situations. In other cases the terminal portions of some of the leaf blades were dead, but this did not necessarily indicate a weakened condition of the plant. The seedling stand, before and after grazing, is shown in Tables X and XI.

TABLE X.—*Record of native forage seedling stand at high elevations after August 15, preceding grazing*

Quadrat No.	Character of vegetation in and around quadrat within radius of 10 feet.[b]	Density of vegetation.[a] Within quadrat.	Density of vegetation.[a] Outside quadrat.	Character of soil.	Slope and exposure.	Total number of seedlings in quadrat.	Number of plants of each seedling species.	Condition of seedlings at time of observation.
1	Mountain bunch-grass and sickle sedge.	4/10	3/10	Coarse gravelly loam	15° west	194	193 Mountain bunch-grass... 1 Sickle sedge	Good.
2	do	2/10	1/10	Clay loam with some gravel.[c]	25° west	277	277 Mountain bunch-grass	Some showed effects of drought.[c]
3	Mountain bunch-grass, sickle sedge, and western porcupine grass.	1/10	Denuded.	do	do	152	149 Mountain bunch-grass... 2 Western porcupine grass 1 Sickle sedge	Do.
4	do	5/10	do	Clay loam	16° west	43	43 Mountain bunch-grass	Good.
5	do	4/10	5/10	Gravelly clay loam	18° west	572	560 Mountain bunch-grass... ... Elk-grass	Fair, but competition had restricted their growth.
6	Mountain bunch-grass, little bluegrass, and sickle sedge.	3/10	1/10	Deep loam rich in organic matter.	13° south	295	295 Mountain bunch-grass	Fair; about 1/10 stand dead.
7	do	2/10	1/10	Clay loam	14° south	140	137 Mountain bunch-grass... 3 Sickle sedge	Good.
8	Mountain bunch-grass	3/10	5/10	Gravelly clay loam	20° west	379	379 Mountain bunch-grass	Portions of quadrat contained too dense growth for best development.
9	do	1/10	Denuded.	Very coarse gravelly loam.	do	193	193 Mountain bunch-grass	Fair; some of terminal leaf blades dead.
10	Mountain bunch-grass, western porcupine grass, and sickle sedge.	5/10	do	do	19° west	320	310 Mountain bunch-grass... 5 Western porcupine grass 5 Sickle sedge	Vigorous.
11	Mountain bunch-grass and wild buckwheat.	3/10	1/10	Clay loam	22° west	214	212 Mountain bunch-grass... 2 Sickle sedge	Fair; many seedlings had previously died.[d]
12	Mountain bunch-grass	3/10	2/10	Gravelly loam	18° west	152	149 Mountain bunch-grass... 3 Sickle sedge	Good.
13	Mountain bunch-grass and sickle sedge.	5/10	5/10	Clay loam	16° west	96	93 Mountain bunch-grass... 2 Sickle sedge 1 Sedge	Thrifty.
14	do	1/10	3/10	Gravelly clay loam	28.5° west	272	271 Mountain bunch-grass... 1 Sickle sedge	Rather poor for lack of water.[e]

[a] To represent the density of growth, 10 is taken as complete ground cover.
[b] Only the most predominant species are recorded. They are arranged in their order of abundance.
[c] Soil lacking in organic matter.
[d] Soil had washed slightly.
[e] Gullying had been rather severe surrounding quadrat.

TABLE X.—*Record of native forage seedling stand at high elevation after August 15, preceding grazing*—Continued

Quadrat No.	Character of vegetation in and around quadrat within radius of 10 feet.	Density of vegetation.		Character of soil.	Slope and exposure.	Total number of seedlings in quadrat.	Number of plants of each seedling species.	Condition of seedlings at time of observation.
		Within quadrat.	Outside quadrat.					
15	Western porcupine grass, mountain bunch-grass, and sickle sedge.	Denuded.	2/10	Gravelly clay loam	16° west	90	85 Western porcupine grass 5 Sickle sedge	Vigorous.
16	Western porcupine grass, mountain bunch-grass, yarrow, and wild buckwheat.	3/10	5/10	Clay loam with little gravel.	3° south	130	121 Western porcupine grass 9 Yarrow	Do.
17	Mountain bunch-grass, western porcupine grass, and sickle sedge.	5/10	4/10	Clay loam	3° southwest	243	240 Western porcupine grass 2 Yarrow 1 Sickle sedge	Fair.
18	Western porcupine grass and mountain bunch-grass.	6/10	6/10	Clay loam	4° south	228	222 Western porcupine grass. 4 Sickle sedge 2 Mountain bunch-grass	Vigorous.
19	.....do.....	1/10	3/10	Fine clay loam	5° southwest	295	267 Western porcupine grass. 27 Mountain bunch-grass 1 Sickle sedge	Poor.
20	Western porcupine grass, yarrow, and mountain bunch-grass.	2/10	3/10	Very coarse, gravelly loam.	4° south	172	169 Western porcupine grass. 3 Mountain bunch-grass	Medium.
21	Western porcupine grass, mountain bunch-grass, and blue beardtongue.	1/10	2/10	Clay loam	5° southwest	52	52 Western porcupine grass.	Exceptionally vigorous.
22	Western porcupine grass, mountain bunch-grass, yarrow, and alum-root.	5/10	3/10	Coarse gravelly loam	3° south	320	312 Western porcupine grass. 6 Mountain bunch-grass 2 Sickle sedge	Competition too strong; many very weak.[a]
23	Western porcupine grass, mountain bunch-grass, and blue beardtongue.	5/10	1/10	Gravelly clay loam	4° south	169	166 Western porcupine grass. 2 Mountain bunch-grass 1 Sickle sedge	Good; above average.
24	Mountain bunch-grass, western porcupine grass, and yarrow.	5/10	1/10	.....do.....	1° south	218	195 Western porcupine grass. 21 Mountain bunch-grass 2 Sickle sedge	Good.
25	Western porcupine grass, mountain bunch-grass, and yarrow.	3/10	2/10	Very light gravelly loam.	4° south	145	129 Western porcupine grass. 13 Mountain bunch-grass 3 Elk-grass	Fair; some partly died back.
26	Mountain bunch-grass, western porcupine grass, and white foxtail.	1/10	1/10	Very coarse, gravelly clay loam.	4° east	52	27 Mountain bunch-grass 23 Western porcupine grass. 2 Sickle sedge	Some of mountain bunch-grass seedlings not vigorous.

27	Mountain bunch-grass, western porcupine grass, and blue beardtongue.	Denuded.	4/10	Light clay loam	3° southeast	103	81 Mountain bunch-grass 17 Western porcupine grass. 5 Sedges	Good.
28	Mountain bunch-grass and sickle sedge.	1/10	2/10	Scab and coarse gravelly loam.	4° east	32	24 Mountain bunch-grass 4 Sickle sedge 4 Western porcupine grass.	Do.
29	Mountain bunch-grass and western porcupine grass.	5/10	5/10	Clay loam	10° south	145	71 Western porcupine grass. 68 Mountain bunch-grass 6 Sickle sedge	Vigorous.
30	Western porcupine grass, mountain bunch-grass, and wild buckwheat.	5/10	2/10	Very coarse gravelly loam.	5° southeast	278	254 Western porcupine grass. 19 Mountain bunch-grass 5 Short-awned brome-grass.	Medium.
31	Western porcupine grass and mountain bunch-grass.	Denuded.	3/10	Coarse gravelly clay loam.	11° southeast	486	417 Western porcupine grass. 68 Mountain bunch-grass 1 Elk-grass	Medium; seedlings too thick in places.[b]
32	Short-awned brome-grass, western porcupine grass, mountain bunch-grass, and wild buckwheat.	2/10	3/10	do	6° east	66	51 Short-awned brome-grass 6 Western porcupine grass. 5 Sickle sedge 4 Mountain bunch-grass	Excellent.
33	Mountain bunch-grass and western porcupine grass.	1/10	2/10	do	9° south	88	83 Western porcupine grass. 4 Mountain bunch-grass 1 Sickle sedge	Medium; some show severe effects from drought.
34	Mountain bunch-grass, smooth wild rye, and western porcupine grass.	1/10	6/10	Scabby, gravelly loam	2° southeast	54	42 Smooth wild rye 6 Western porcupine grass 3 Mountain bunch-grass 3 Sickle sedge	Rye-grass seedlings so tall as to furnish forage.
35	Smooth wild rye, western porcupine grass, and mountain bunch-grass.	1/10	5/10	Gravelly loam	12° south	73	46 Smooth wild rye 25 Western porcupine grass. 2 Sickle sedge	Good.
36	Mountain bunch-grass, western porcupine grass, and smooth wild rye.	2/10	4/10	Coarse, gravelly clay loam.	2° southeast	101	81 Smooth wild rye 9 Western porcupine grass. 7 Mountain bunch-grass 4 Sickle sedge	Medium.
37	Western porcupine grass, mountain bunch-grass, smooth wild rye, and sickle sedge.	1/10	5/10	Rocky "scabland," with shallow loam.	10° south	246	220 Western porcupine grass. 14 Mountain bunch-grass 10 Sickle sedge 2 Smooth wild rye	Vigorous.
38	Smooth wild rye and little bluegrass.	(c)	2/10	do	4° southeast	37	31 Smooth wild rye 3 Little bluegrass 3 Yarrow	Vigorous; little bluegrass somewhat weak.
39	Western porcupine grass, mountain bunch-grass, and yarrow.	3/10	2/10	Very coarse gravelly loam.	14° south	217	213 Western porcupine grass. 3 Mountain bunch-grass 1 Yarrow	Good; have made exceptional growth.
40	Little bluegrass, big bunch-grass, and slender hair-grass.	1/10	4/10	Fine, gravelly clay loam.[d]	Level	135	120 Little bluegrass 12 Slender hair-grass 1 Smooth wild rye 1 Yarrow 1 Big bunch-grass	Drought has weakened many.

[a] Soil had washed slightly; seedlings too thick.
[b] Root competition severe in some parts of quadrat.
[c] Nothing but seedlings.
[d] Soil compact and somewhat baked.

TABLE X.—*Record of native forage seedling stand at high elevation after August 15, preceding grazing*—Continued

Quadrat No.	Character of vegetation in and around quadrat within radius of 10 feet.	Density of vegetation.		Character of soil.	Slope and exposure.	Total number of seedlings in quadrat.	Number of plants of each seedling species.	Condition of seedlings at time of observation.
		Within quadrat.	Outside quadrat.					
41	Western porcupine grass, small bluegrass, mountain bunch-grass, and blue beardtongue.	Denuded.		Clay loam	12.5° south	78	62 Porcupine grass. 7 Little bluegrass. 5 Blue foxglove. 3 Smooth wild rye. 1 Yarrow.	Good.
42	Little bluegrass, short-awned brome-grass, and mountain bunch-grass.	1/10	3/10	Clay loam	11.5° south	185	148 Little bluegrass. 13 Yarrow. 11 Short-awned brome-grass. 10 Smooth wild rye. 3 Mountain bunch-grass.	Little bluegrass; poor for lack of water.
43	Mountain bunch-grass, western porcupine grass, and sickle sedge.	2/10	4/10	Gravelly clay loam	14° south	94	81 Western porcupine grass. 5 Little bluegrass. 5 Sickle sedge. 3 Mountain bunch-grass.	Medium.
44	Smooth wild rye, yarrow, and mountain dandelion.	5/10	2/10	Clay loam	4° south	204	180 Smooth wild rye. 13 Mountain dandelion. 11 Yarrow.	Do.
45	Western porcupine grass, mountain bunch-grass, and blue beardtongue.	Denuded.	5/10	Scabby soil, shallow loam.	9° west	321	321 Western porcupine grass.	Rather badly wilted.
46	Mountain bunch-grass, little bluegrass, yarrow, and blue beardtongue.	1/10	4/10	Clay loam[a]	3° south	74	57 Mountain bunch-grass. 13 Mountain dandelion. 3 Yarrow. 1 Blue beardtongue.	Fair; some roots gullied out of ground.
47	Western porcupine grass, smooth wild rye, and mountain bunch-grass.	1/10	4/10	Gravelly clay loam	11° south	87	61 Western porcupine grass. 23 Alpine redtop. 3 Smooth wild rye.	Very good.
48	Mountain bunch-grass, western porcupine grass, and big bunch-grass.	1/10	2/10	Very coarse, gravelly clay loam.	3° south	36	28 Mountain bunch-grass. 5 Yarrow. 2 Big bunch-grass. 1 Smooth wild rye.	Do.
49	Western porcupine grass, mountain bunch-grass, smooth wild rye, and yarrow.	1/10	6/10	Gravelly clay loam	9° south	287	274 Western porcupine grass. 9 Yarrow. 4 Mountain bunch-grass.	Good.

50	Smooth wild rye, mountain bunch-grass, and yarrow.	1/10	6/10	....do....	1° south	67	49 Smooth wild rye. 16 Yarrow. 2 Mountain bunch-grass.	Do.
51	Western porcupine grass, mountain bunch-grass, and yarrow.	1/10	1/10	Rocky gravelly loam	13° south	166	142 Western porcupine grass. 18 Mountain bunch-grass. 6 Sickle sedge.	Medium. Many had previously died.
52	Mountain bunch-grass and a number of annual weeds.	1/10	3/10	....do....	8° south	24	24 Mountain bunch-grass.	Generally good.
53	Mountain bunch-grass and yarrow.	2. 5/10	2/10	Scabby clay loam	13° east	39	34 Mountain bunch-grass. 5 Sickle sedge.	Medium.
54	Mountain bunch-grass and western porcupine grass.	1/10	3/10	....do....	4° east	36	30 Mountain bunch-grass. 5 Western porcupine grass. 1 Sedge.	Excellent.
55	Western porcupine grass and annual weeds.	4/10	2/10	Rocky clay loam [b]	10° east	321	321 Western porcupine grass.	Very poor, 50 per cent having previously died.
56	Mountain bunch-grass, western porcupine grass, and short-awned brome-grass.	2/10	3/10	Rocky, gravelly clay loam.	3° east	33	28 Mountain bunch-grass. 3 Western porcupine grass. 2 Short-awned brome-grass	Good.
57	Mountain bunch-grass	5/10	5/10	Clay loam	9° east	32	32 Mountain bunch-grass.	Vigorous.
58	Mountain bunch-grass and western porcupine grass.	2/10	1/10	Rocky clay loam	5° east	45	40 Mountain bunch-grass. 5 Western porcupine grass.	Good.
59	Mountain bunch-grass and western porcupine grass.	2. 5/10	2/10	Clay loam	22° east	27	17 Mountain bunch-grass. 9 Western porcupine grass. 1 Sickle sedge.	Medium.
60	Mountain bunch-grass	2/10	1/10	Deep clay loam [c]	6° east	30	29 Mountain bunch-grass. 1 Western porcupine grass.	Vigorous; unusually large.
61	....do....	1/10	1/10	....do....	7° east	29	29 Mountain bunch-grass.	Vigorous.
62	Mountain bunch-grass and western porcupine grass.	1/10	2/10	Gravelly clay	8° east	35	34 Mountain bunch-grass. 1 Western porcupine grass.	Good.
	Average seedling stand					155.3		

[a] Surface soil removed by washing to depth of 2 inches.
[b] Soil very dry; terminal part of many leaf blades dead.
[c] Soil very compact and slightly baked.

TABLE XI.—*Record of native forage seedling stand at high elevations after September 1, after grazing*

Quadrat No.	Total number of seedlings remaining.	Total loss.	Percentage lost.	Number found dead.	Number not accounted for.	Number of plants of remaining seedling species.	Number whose recovery seemed doubtful.[a]	Condition of remaining seedling stand at time of recount.	Remarks.
1	119	75	38.6	6	69	119 Mountain bunch-grass	3	Much weakened through close grazing and trailing.	
2	162	115	41.5	10	105	162 Mountain bunch-grass	6	....do	
3	81	71	46.7	3	68	80 Mountain bunch-grass 1 Western porcupine grass		Fair; showed lack of moisture.	
4	26	17	39.5	2	15	26 Mountain bunch-grass	1	Medium strong	
5	248	324	56.6	15	309	244 Mountain bunch-grass 4 Elk-grass	21	Medium; closely grazed	Drought had previously impaired the seedling growth.
6	122	173	58.6	3	168	122 Mountain bunch-grass	33	Vigorous	
7	54	86	61.4	7	89	53 Mountain bunch-grass 1 Sickle sedge	5	Generally strong, some much weakened.	
8	183	196	51.7	23	173	183 Mountain bunch-grass	11	Fair	Severely grazed.
9	96	87	47.5	2	85	96 Mountain bunch-grass	8	Fair; seedlings previously weakened for lack of water.	
10	147	173	54.0	6	167	145 Mountain bunch-grass 1 Western porcupine grass 1 Sickle sedge	7	Fair	
11	94	120	56.0	10	110	193 Mountain bunch-grass 1 Sickle sedge	4	Terminal part of some leaf blades dead.	Washing of soil had exposed some of the seedling roots.
12	89	63	41.4	4	59	89 Mountain bunch-grass	5	Thrifty	
13	59	37	38.5	2	35	58 Mountain bunch-grass 1 Sickle sedge	2	Seedlings much weakened for lack of water.	
14	116	56	32.5	4	52	116 Mountain bunch-grass	4	Vigorous	
15	45	45	50.0	.....	45	44 Western porcupine grass 1 Sickle sedge	4	.....do	
16	68	62	47.7	12	50	61 Western porcupine grass 7 Yarrow	6	Medium strong	Weakness of seedlings due, in part, to poor moisture conditions.
17	107	136	55.9	3	133	105 Western porcupine grass 2 Yarrow	.....	Vigorous	
18	145	83	36.4	11	72	140 Western porcupine grass 2 Mountain bunch-grass 3 Sickle sedge	5	.....do	
19	123	172	58.3	2	170	122 Western porcupine grass 1 Sickle sedge	.....	Most of seedlings weak	
20	96	76	44.2	13	63	95 Western porcupine grass 1 Mountain bunch-grass	7	Fair; poor soil and drought the main cause.	
21	30	22	42.3	8	14	30 Western porcupine grass	4	Vigorous	

22	204	116	36.2	4	112	198 Western porcupine grass 6 Mountain bunch-grass	2	Weakened badly by trampling.	Many roots exposed because of trampling and close seedling stand.
23	101	68	40.2	9	59	100 Western porcupine grass 1 Sickle sedge	1	Medium vigorous	
24	117	101	46.3	3	98	111 Western porcupine grass 6 Mountain bunch-grass	3	Good	
25	69	76	52.4	2	74	60 Western porcupine grass 7 Mountain bunch-grass 2 Sickle sedge	7	Fair; closely grazed	
26	17	35	67.3	3	32	9 Western porcupine grass 8 Mountain bunch-grass	3	Poor	Sheep had trailed through quadrat, destroying many seedlings.
27	30	73	70.8	6	67	29 Mountain bunch-grass 1 Western porcupine grass 8 Mountain bunch-grass	2	Good	
28	14	18	56.2	4	14	5 Western pocupine grass 1 Sickle sedge	4	Much weakened	
29	72	73	50.3	2	71	50 Western porcupine grass 20 Mountain bunch-grass 2 Sickle sedge	1	Severely trampled and weakened.	
30	140	139	49.8	3	136	132 Western porcupine grass 5 Mountain bunch-grass 3 Short-awned brome-grass	3	Vigorous	
31	133	353	72.6	11	342	116 Western porcupine grass 17 Mountain bunch-grass	4	Severely trampled; quadrat on public sheep trail.	Seedlings previously weakened through competition and drought.
32	34	32	48.4	3	29	30 Short-awned brome-grass 3 Western porcupine grass 1 Mountain bunch-grass	3	Vigorous	
33	60	28	31.8	6	22	59 Western porcupine grass 1 Mountain bunch-grass	1	.....do	
34	45	9	16.6	7	2	40 Smooth wild rye 3 Mountain bunch-grass 2 Western porcupine grass	8	Smooth wild rye has made unusual height growth. Vigorous.	Had escaped close grazing.
35	37	36	49.3	1	35	30 Smooth wild rye 7 Western porcupine grass	3	Fair; showed effects of trampling.	
36	66	35	34.6	11	24	61 Smooth wild rye 3 Western porcupine grass 2 Mountain bunch-grass	7	Good	
37	92	154	62.6	5	149	134 Western porcupine grass 4 Mountain bunch-grass 1 Sickle sedge	4	Many seedlings eaten off and partly pulled out of ground.	
38	29	8	21.6	4	4	27 Smooth wild rye 2 Little bluegrass		Medium strong	
39	137	80	36.8	.....	80	134 Western porcupine grass 3 Mountain bunch-grass		Vigorous	

a Of the seedlings whose recovery from grazing, drought, or other causes was doubtful, none were included in the number composing the "total number of seedlings remaining," as shown in column 2 of this table.

TABLE XI.—*Record of native forage seedling stand at high elevations after September 1, after grazing*—Continued

Quadrat No.	Total number of seedlings remaining.	Total loss.	Percentage lost.	Number found dead.	Number not accounted for.	Number of plants of remaining seedling species.	Number whose recovery seemed doubtful.	Condition of remaining seedling stand at time of recount.	Remarks.
40	118	17	12.5	4	12	112 Little bluegrass 5 Slender hair-grass 1 Yarrow	14	A few weak, most of them vigorous.	Greatest injury to seedlings due to early drought period.
41	45	33	42.3	7	26	31 Western porcupine grass 7 Little bluegrass 4 Blue beardtongue 3 Smooth wild rye	5	Vigorous; had produced unusual growth in height.	
42	155	30	16.2	18	12	138 Little bluegrass 9 Smooth wild rye 6 Yarrow 2 Mountain bunch-grass	8	Vigorous	
43	70	24	25.5	3	21	57 Western porcupine grass 5 Little bluegrass 5 Sickle sedge 3 Mountain bunch-grass		A few doubtful of recovery; others vigorous.	
44	148	56	27.4	15	41	128 Smooth wild rye 11 Yarrow 9 Mountain dandelion	2	Vigorous	
45	171	150	46.7	12	137	171 Western porcupine grass		Good	
46	20	54	72.9	4	50	9 Mountain bunch-grass 7 Mountain dandelion 4 Yarrow	4	Medium	Seedlings weakened through the gullying of the soil.
47	51	38	42.7	4	34	44 Western porcupine grass 6 Alpine redtop 1 Smooth wild rye	6	Vigorous	
48	31	3	8.8		3	29 Mountain bunch-grass 2 Yarrow	6	do	
49	165	122	42.5	6	116	163 Western porcupine grass 2 Yarrow	4	do	
50	44	23	34.3	2	21	29 Smooth wild rye 14 Yarrow 1 Mountain bunch-grass	2	do	Some seedlings destroyed by gopher mounds.
51	41	124	74.7		124	36 Western porcupine grass 5 Mountain bunch-grass	10	Medium	Sheep trail through quadrat responsible for heavy loss.
52	13	11	45.8	8	3	13 Mountain bunch-grass	1	Vigorous	
53	23	16	41.0	4	12	21 Mountain bunch-grass 2 Sickle sedge		Medium; showed effects of drought.	
54	5	31	86.1		31	4 Mountain bunch-grass 1 Sickle sedge		Excellent	

55	91	230	71.6	18	212	91 Western porcupine grass	1	Very poor	Drought had severely weakened seedlings early in season.
56	15	18	54.5	2	16	13 Mountain bunch-grass 2 Western porcupine grass		Good	
57	9	23	71.8	2	21	9 Mountain bunch-grass		Vigorous	
58	14	31	68.8	3	28	10 Mountain bunch-grass 4 Western porcupine grass		do	
59	10	17	62.9	2	15	7 Mountain bunch-grass 2 Western porcupine grass 1 Sickle sedge	1	Medium strong	
60	17	13	43.3	.....	13	17 Mountain bunch-grass	1	Vigorous	Soil firm and remaining seedlings little injured by trampling.
61	18	11	37.9	4	7	18 Mountain bunch-grass	3	Vigorous; have made unusual growth in height.	
62	11	24	68.5	3	21	11 Mountain bunch-grass		Vigorous	Narrow trail made through quadrat, killing all seedlings in its path.
Average..	80.5	74.5	48.2						

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It will be seen that both before and after grazing the more abundant seedlings were of mountain bunch-grass, smooth wild rye, short-awned brome-grass, sickle sedge, little bluegrass, and western porcupine grass. Table X shows that before grazing there was an average for all quadrats of 155.3 seedlings per square meter. After grazing (Table XI) this was reduced to 80.5 seedlings, a loss of 48.2 per cent. A comparison of the height and root development of the same seedling species at medium and high elevations discloses the fact that the shorter and later growing season of the high range had not been conducive to the rapid development made by the seedlings in the lower and warmer, though drier, situations. Though the high ranges were grazed much more moderately, the loss was practically the same as on the lower ones.

The factors responsible for the heaviest loss of seedlings through grazing were (1) superabundance of soil moisture, (2) lack of soil moisture, (3) abnormally dense seedling stands, and (4) irregular topography.

In wet situations the roots did not penetrate as deeply as in the more compact and drier soils, and so were more easily disturbed. Although in some cases the seedlings recovered, the loss on the moist soils was relatively large, in fact occasionally five times that on the dry soils.

In excessively dry situations the loss from grazing was often serious, owing to the relatively weak growth made by the seedlings and their poor recuperative power. In some places practically the entire seedling stand was destroyed. Doubtless many of the seedlings whose destruction was charged to grazing would have perished in any event from drought, though the stand as a whole was not affected by this factor. The lack of vigor in individual plants where the stand was unusually dense often caused a heavy loss. Quadrats with from 250 to 500 seedlings almost invariably suffered more than the contiguous plots which carried a sparser stand. In general, it may be said that more than 200 seedlings to a square meter is a heavier stand than most situations can support permanently. Competition is most severe between plants of the same species, since each plant makes the same demand upon the habitat. Where a dense stand occurred it was usually of a single species.

The loss from trampling was much more severe on steep slopes than on level situations. This was largely the result of the coarser texture of the soils on steep slopes and of the greater extent to which they are shifted by grazing. Moreover, because of the lack of soil moisture on many of the steeper slopes, the plants growing there are generally less vigorous than those growing in more level places.

TIME AND INTENSITY OF GRAZING AFTER THE FIRST YEAR

Though the information here presented shows that the range upon which deferred grazing was practiced suffered heavy loss of seedlings when moderately grazed, it should not be concluded that in order to

insure permanent improvement grazing must be suspended from the time the first seed crop is produced until the seedlings become established. Notwithstanding the fact that half the stand in existence in the autumn is likely to be eliminated by grazing, the planting of an additional seed crop will, as a rule, fully offset this loss.

The time at which the seed crop of the established vegetation reaches maturity, marking the approximate limit of growth and occurring in the region studied about September 1, is the beginning of the period when the range may be grazed with the least injury to forage seedlings. During the four weeks prior to this period the root system almost doubles its growth and strength.

On account of the much more elaborately developed root system at the end of the second year of the seedlings' growth, the loss through grazing at that period perceptibly lessens. Even then, however, the range should not be grazed prior to the maturity of the seed crop. Restriction of grazing to the period following seed maturity will give both the 1- and 2-year-old plants sufficient protection to insure the restocking of the range.

To sum up the conclusions regarding deferred grazing, it may be said that the system has proved highly successful wherever an adequate seed crop was produced. Its advantages over yearlong grazing and yearlong protection are (1) the restoration and maintenance of the vegetation without the loss of the forage crop in any year, (2) the planting of the seed, and (3) the removal of the vegetation itself, thus minimizing the fire danger from an accumulation of inflammable material.

Deferred grazing has all the advantages of complete protection, so far as the rejuvenation of the weakened plants is concerned; and, if overstocking and abusive management are guarded against, the system will work no material injury to forest reproduction or watersheds. It is believed, therefore, that the principles of deferred grazing, with whatever modifications are necessary to meet local conditions, should be applied to the management of all ranges.

APPLICATION OF DEFERRED GRAZING SYSTEM TO RANGE MANAGEMENT

WHERE APPLICABLE

If grazing lands are to be fully revegetated within a reasonable time, the range lands must, of course, support at the outset at least a sparse stand of the species valuable for grazing and revegetation purposes. In the Wallowa Mountains, where mountain bunch-grass constitutes the predominating herbage, a satisfactory seed crop and subsequent seedling stand were secured where the original tussocks stood as far apart as 6 feet. Where grazing has been so severe as to destroy the major portion of the original vegetation, the remaining plants may not produce

viable seed until after they have regained their lost vigor, a matter of one or two seasons. On other sparsely vegetated lands, however, a stand of from 15 to 30 seedlings per meter, which is a satisfactory density on most soils, has been secured after the first year of deferred grazing.

The benefits of deferred grazing are not confined to areas which support plants of strong seed habits or those where the climate is particularly favorable to growth. Though on areas near and above timber line, where most of the forage plants reproduce vegetatively instead of by seed, deferred grazing does not tend to augment vegetation as it does on areas where the plants reproduce by the latter method, it does result in a permanent increase in vigor of the range plants and so promotes vegetative reproduction, which otherwise would be held in check by the premature removal of the herbage each season. In short, given a sufficient number of the original plants, deferred grazing is applicable wherever the vegetation is palatable after the seed crop has ripened and where water facilities will permit the range to be used in the autumn.

Before the deferred grazing system was thoroughly tried out, certain stockmen maintained that after seed maturity the palatability and nutritiousness of the herbage would be low and therefore that the season's forage crop would not only be wasted, but stockmen might be induced to keep their animals in the mountains until so late in the season that on account of the resultant loss of weight they would not be able to market them direct from the summer range.

To determine definitely the nutritive value of the forage after seed maturity, chemical analyses were made of the foliage of mountain bunch-grass, first, when the flower stalks were being produced, and again, at the time the seed ripened. The average of the tests showed that the young growing plant is 27.21 per cent richer in ether extract (fat) than the mature plant, while the latter slightly exceeds the former in protein (nitrogen). The mature plant also contains more crude fiber, but since the flower stalks are not consumed after the seeds are ripened that part of each specimen was eliminated from the tests. In comparison with timothy hay, mature mountain bunch-grass contains 94.39 per cent more protein, practically the same amount of ether extract, and 50.45 per cent less crude fiber, the last-named material being practically indigestible.

Nearly all the leading range plants, particularly the grasses, are grazed during the autumn with relish. It can not be said, however, that they are eaten with the same gusto after seed maturity as when they are growing vigorously. It was found that the first time a band of sheep passed over a matured range of medium density only about half of the forage crop was grazed off. Not until the range was grazed a second or third time was the crop entirely consumed. The vegetation on similar ranges grazed a month earlier was in most cases entirely con-

sumed the first time the stock passed over it. On ranges grazed after seed maturity the naked flower stalks, rising from leafless tufts of bunchgrass, remained after the stock had passed over them, but on ranges grazed when the forage was succulent and tender no flower stalks were visible after the passage of the stock. No appreciable amount of herbage remained on either area.

Sheep from several allotments where deferred grazing was practiced made fully as good progress as other sheep in allotments not handled under deferred grazing. By the time the seed has ripened, the milk flow of the ewes is nominal, and though it may decrease slightly when the animals are placed on the semi-air-cured forage, the lambs by this time are 4 or 5 months old, and milk is secondary to the nourishment secured through cropping.

Deferred grazing does not materially change the character of the forage on mountain ranges after seed maturity, because by this time succulent forage everywhere has been reduced to a minimum, leaving only the air-cured plants and on open grazing lands a small amount of second growth. By protecting part of the range until the last few weeks of the grazing season there is the possible advantage of having a reserve supply of solid feed upon which to harden the stock prior to the drive to market or to winter range.

The water facilities of the range may be an important consideration in determining whether or not to adopt the deferred grazing system. Regardless of the palatability of the forage, deferred grazing can not be carried out unless there is an adequate supply of water. On many ranges the water facilities may be improved by the construction of dams, the development and protection of springs, and even by digging wells and building windmills. Springs and small mountain streams are often replenished by the autumn rains.

SELECTION OF LANDS

The amount of range needed for grazing under the deferred system depends upon (1) the time at which the seed of the important forage plants matures and (2) the portion of the grazing season remaining after seed maturity. In the mountains of northeastern Oregon one-fifth of the grazing season remains after seed maturity. Accordingly, one-fifth of the carrying capacity, but not necessarily of the total acreage, of each grazing allotment may be reserved annually for purposes of revegetation. The lower the elevation the earlier, of course, does the seed mature and the greater the proportion of range which must be reserved for deferred grazing. Since the lands are usually grazed by camps, the carrying capacity of which is well known, the user will have no difficulty in determining what proportion of the range should be reserved.

MANAGEMENT DURING THE REVEGATION PERIOD

Once the area in need of revegetation has been selected, no stock should be allowed to graze on it until after the seed has ripened. Efforts should then be made to have the stock pass at least once over the entire area reserved, in order thoroughly to plant the seed.

In the second year of deferred grazing if a reasonably dense stand of forage seedlings has been secured, abusive herding must be avoided. While it may do no apparent harm, so far as future seed crops are concerned, to fully utilize the forage in the fall after the first year of protection, the loss of seedlings, even when the range is only moderately grazed, amounts to about 50 per cent. Close grazing and carelessness in permitting the stock to bunch and trail must necessarily increase this loss. Therefore, while close grazing after seed maturity the second year may result in increasing the forage seedling stand the following season, such an increase could only be temporary, since the practice causes severe loss among the seedlings already in existence. Moderate grazing after seed maturity also, of course, results in the destruction of a large number of seedlings, but the double advantage of utilizing the forage and planting an additional seed crop readily offsets this loss. Moderate grazing should be practiced in the second and subsequent seasons until the plants have reached full maturity and are permanently established. In the case of perennial plants this period is three years.

When the area selected has been thoroughly reseeded and the plants permanently established, another area in need of reseeding should be selected. This system should not come to an end when the range has been completely reseeded, but should be kept up in order to thoroughly maintain the vigor of the vegetation and allow for an occasional seed crop.

During the season of 1912 deferred grazing was in effect on 10 allotments in various portions of the Wallowa National Forest. In every case the carrying capacity of the range has increased materially, and the best interests of the stock industry seem to call for the adoption of the system generally.

SUMMARY

(1) Normally the spring growth of forage plants begins in the Hudsonian zone about June 25. For each 1,000 feet decrease in elevation this period comes approximately seven days earlier.

(2) In the Wallowa Mountains the flower stalks are produced approximately between July 15 and August 10, while the seed matures between August 15 and September 1.

(3) Even under the most favorable conditions the viability of the seed on summer ranges is relatively low.

(4) Removal of the herbage year after year during the early part of the growing season weakens the plants, delays the resumption of growth,

advances the time of maturity, and decreases the seed production and the fertility of the seed.

(5) Grazing after seed maturity in no way interferes with flower-stalk production. As much fertile seed is produced as where the vegetation is protected from grazing during the whole of the year.

(6) Germination of the seed and establishment of seedlings depend largely upon the thoroughness with which the seed is planted. In the case of practically all perennial forage species the soil must be stirred after the seed is dropped if there is to be permanent reproduction.

(7) Even after a fertile seed crop has been planted there is a relatively heavy loss of seedlings as a result of soil heaving. After the first season, however, the loss due to climatic conditions is negligible.

(8) When 3 years old, perennial plants usually produce flower stalks and mature fertile seed.

(9) Under the practice of yearlong or season-long grazing both the growth of the plants and seed production are seriously interfered with. A range so used, when stocked to its full capacity, finally becomes denuded.

(10) Yearlong protection of the range favors plant growth and seed production, but does not insure the planting of the seed. Moreover, it is impracticable, because of the entire loss of the forage crop and the fire danger resulting from the accumulation of inflammable material.

(11) Deferred grazing insures the planting of the seed crop and the permanent establishment of seedling plants without sacrificing the season's forage or establishing a fire hazard.

(12) Deferred grazing can be applied wherever the vegetation remains palatable after seed maturity and produces a seed crop, provided ample water facilities for stock exist or may be developed.

(13) The proportion of the range which should be set aside for deferred grazing is determined by the time of year the seed matures. In the Wallowa Mountains one-fifth of the summer grazing season remains after the seed has ripened, and hence one-fifth of each range allotment may be grazed after that date.

(14) The distribution of water and the extent of overgrazing will chiefly determine the area upon which grazing should be first deferred.

(15) After the first area selected has been revegetated it may be grazed at the usual time and another area set aside for deferred grazing. This plan of rotation from one area to another should be continued, even after the entire range has been revegetated, in order to maintain the vigor of the forage plants and to allow the production of an occasional seed crop.

PLATE XII

Fig. 1.—View of the lower grazing lands in the Wallowa National Forest. The timber is western yellow pine. The exposed situations are covered with a dense growth of big bunch-grass (*Agropyron spicatum*).

Fig. 2.—Characteristic open stand of western yellow pine and dense cover of herbaceous vegetation, mainly pine-grass (*Calamagrostis pubescens*), Wallowa National Forest. Transition zone (yellow-pine association).

Fig. 3.—A burned-over area of lodgepole pine, with characteristic dense sapling stand.

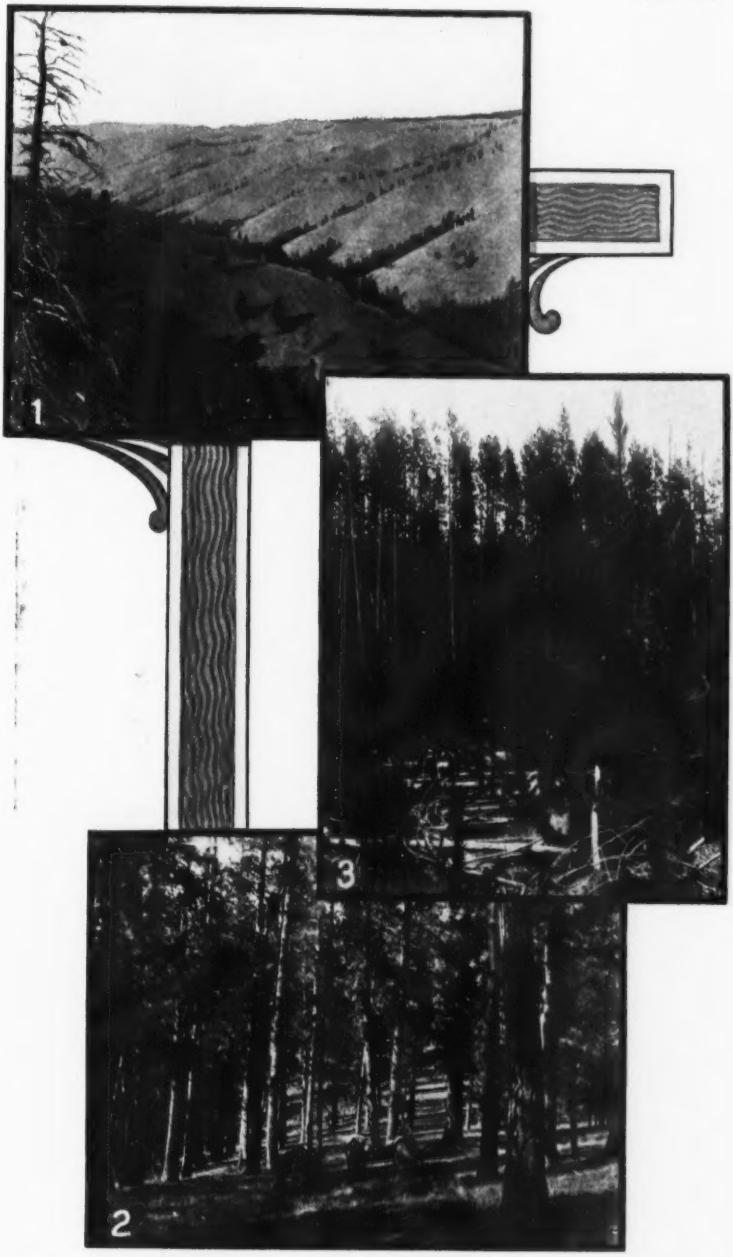
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PLATE XIII

Fig. 1.—Dense stand of lodgepole pine, with undergrowth of red huckleberry (*Vaccinium scoparium*). Canadian zone (lodgepole-pine association).

Fig. 2.—A flat eminence in the Hudsonian zone, showing the characteristic clumped growth of whitebark pine and Alpine fir. The glade land was formerly densely vegetated with mountain bunch-grass.

Fig. 3.—Irregular topography of the upper grazing lands. On northerly exposures snow often remains until August. Photographed on July 25, 1908. Hudsonian zone (whitebark-pine association).

PLATE XIV

Fig. 1.—Arctic-Alpine and upper subalpine region, where forage is sparse, due to poor soil, short growing season, and unfavorable climate.

Fig. 2.—Mountain range lands prior to the beginning of growth and germination. Photographed on June 21, 1908.

Fig. 3.—Same view as shown in figure 2, but more in detail, showing the condition eight days later (June 30). The conspicuous plant in the foreground is spring beauty (*Claytonia lanceolata*), which closely follows the recession of the snow and announces the earliest approach of spring.

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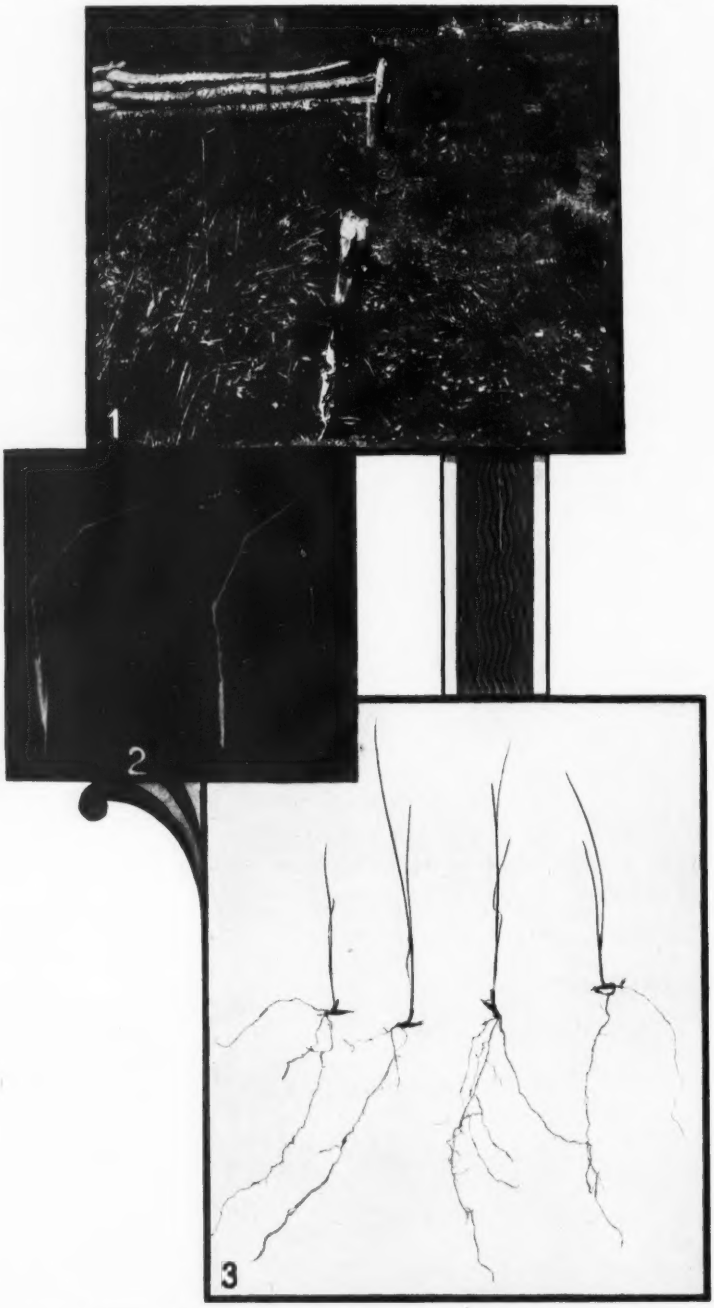
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PLATE XV

Fig. 1.—Contrast in the progress of the flower stalk production of mountain bunch-grass on portion of range which has been completely closed to grazing for a period of three successive years and on range which has been subject to continued early grazing. Section of fence temporarily removed. Photographed on July 7, 1909, before grazing.

Fig. 2.—Western porcupine grass (*Stipa occidentalis*), showing empty glumes and floret with the scale and its awned projection to the left; to the right the floret with glumes removed, showing the sharp-pointed, slightly-curved seed tip. Natural size.

Fig. 3.—Average development of the root system and aerial portion of mountain bunch-grass at end of the first growing season. Natural size.

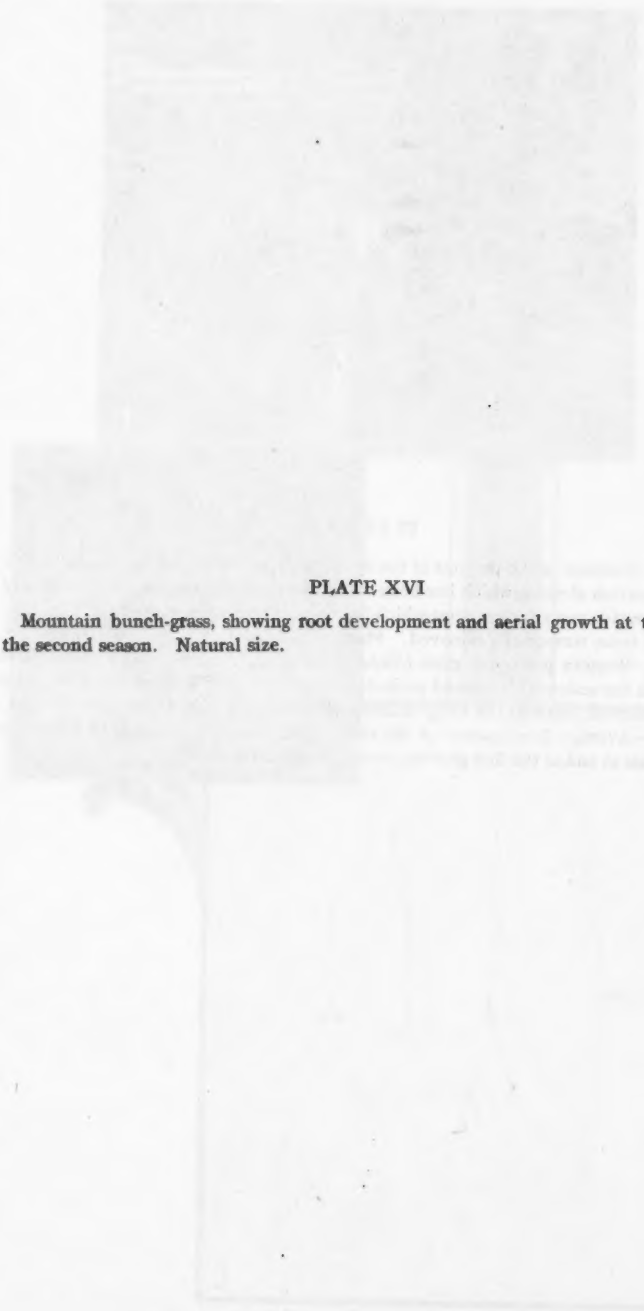

PLATE XVI

Mountain bunch-grass, showing root development and aerial growth at the end of the second season. Natural size.

PLATE XVII

Mountain bunch-grass in the spring of the third year of growth just before producing flower stalks, showing the natural position and length of the elaborate root development and aerial growth. Natural size.

PLATE XVIII

Mountain bunch-grass at the end of the third year, showing three flower stalks and inflorescence. Natural size.

PLATE XIX

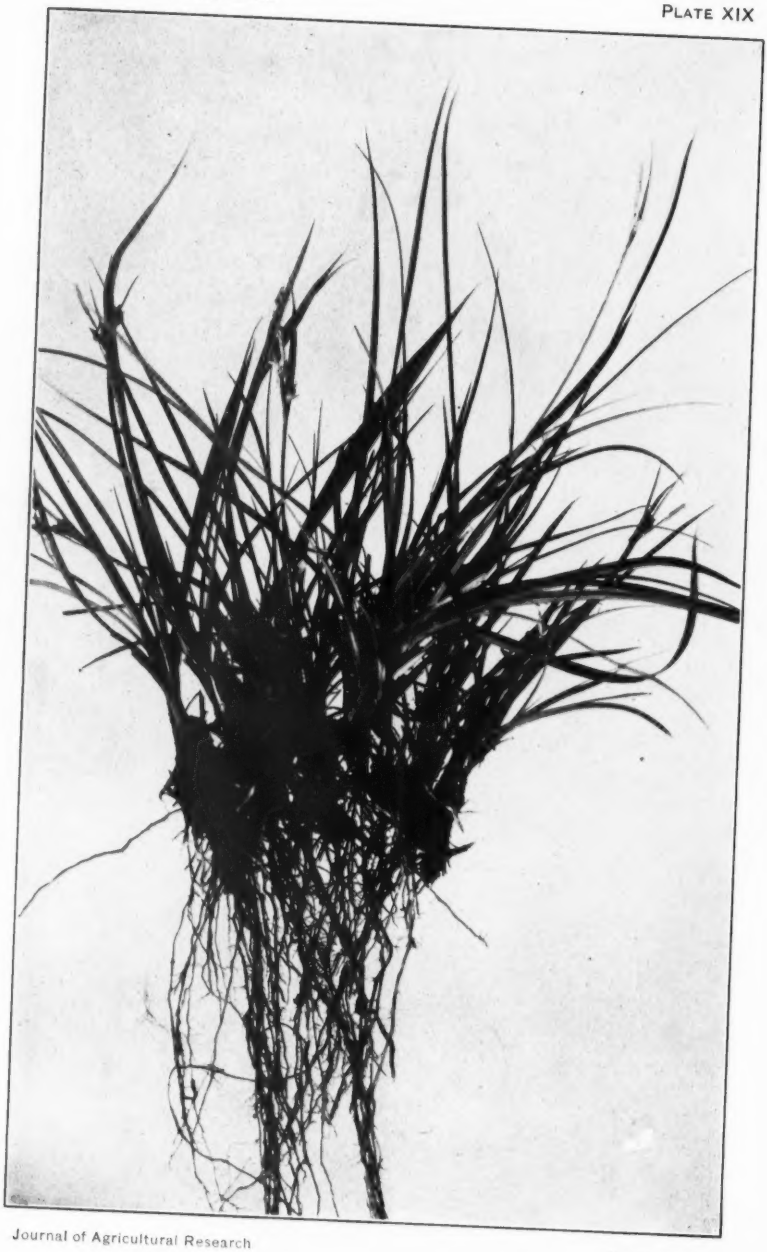

PLATE XIX

Sickle sedge (*Carex umbellata brevirostris*), showing offshoots from the root-stocks and flower stalks with fruit in the process of development. This is an aggressive but unpalatable plant which is reproducing abundantly on overgrazed ranges under the prevailing grazing practice. Natural size.

PLATE XX

Fig. 1.—Station 4 on Stanley Range as it appeared on July 12, 1907. Elevation, 7,400 feet.

Fig. 2.—View of station 4 on July 15, 1909, after two years' protection from grazing animals. The apparent increase in forage is due to luxuriant growth of the vegetation in existence when stock was eliminated and to slight vegetative increase in the grass tufts. No perennial seedlings were found on this area.

Fig. 3.—View of quadrat No. 1, established on July 10, 1907. Annual weeds constitute the predominant vegetation. Elevation, 3,000 feet.

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PLATE XXI

Fig. 1.—Quadrat 1, as it appeared on July 16, 1909. Soft cheat occupies four-fifths of the quadrat, the balance being composed mainly of mountain June-grass, geranium, and yarrow.

Fig. 2.—Area of mountain bunch-grass closed to grazing animals on July 8, 1907. Photographed July 7, 1909. Stanley Range, elevation approximately 7,400 feet.

Fig. 3.—View of open range contiguous to area shown in figure 2. Photographed on July 7, 1909.

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PLATE XXII

View of plot in the Transition (yellow-pine) zone which has been protected from grazing animals for three successive years, showing contrast in carrying capacity with contiguous open range. The increase in stand is due almost entirely to the reproduction of annual plants.

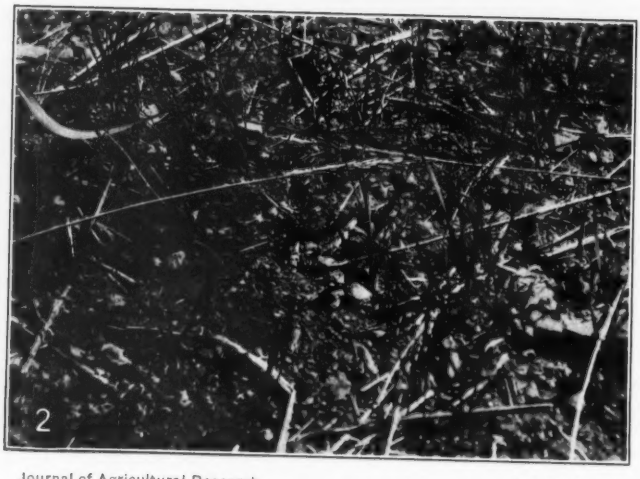

PLATE XXIII

Fig. 1.—View of portion of allotment at medium elevation where the destruction of forage seedlings due to grazing and trampling was studied.

Fig. 2.—Dense stand of smooth wild rye (*Elymus glaucus*) and short-awned bromegrass (*Bromus marginatus*) seedlings. These species were fully 4 inches tall by August 15 and were invariably grazed by sheep on areas comparatively free from other vegetation.

PECAN ROSETTE

By W. A. ORTON, *Pathologist in Charge, Cotton and Truck Disease and Sugar-Plant Investigations, and* FREDERICK V. RAND,[1] *Assistant Pathologist, Laboratory of Plant Pathology, Bureau of Plant Industry*

HISTORY AND DISTRIBUTION

Rosette has been rather generally recognized by growers as a serious disease almost from the inception of commercial pecan orcharding. As early as 1902 requests came to the United States Department of Agriculture for an investigation into the causes of the disease and possible methods of control. The work was at once undertaken by the senior author and carried on for about four years in connection with other

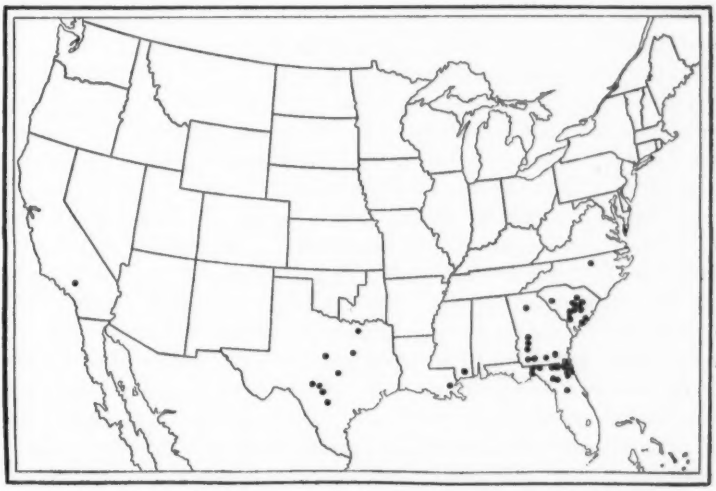

FIG. 1.—Map showing the known distribution of pecan rosette in the United States.

work in the Southern States, but between 1906 and 1910 little attention was paid to the disease. Since 1910, and more particularly during the seasons of 1912 and 1913, the experimentation has been continued by the junior author.

The disease is well distributed over the pecan-growing territory from Texas to the Atlantic coast and from Florida to Virginia. (See fig. 1.) It has been definitely seen by one or the other of the authors at Whittier, Cal.; San Antonio, Boerne, Waring, Kerrville, San Saba, Waco, Austin, McKinney, Tex.; New Orleans, La.; Ocean Springs, Miss.; Atlanta,

[1] The work of the junior author was carried out while he was employed as scientific assistant in the Office of Fruit-Disease Investigations, Bureau of Plant Industry.

Statesboro, Albany, De Witt, Baconton, Thomasville, Cairo, Valdosta, and Blackshear, Ga.; Belleview, Palatka, Sisco, Gainesville, St. Augustine, Jacksonville, McClenny, Glen St. Mary, Alachua, Lake City, Monticello, Newport, and Tallahassee, Fla.; Mt. Pleasant, Denmark, Bamberg, Greenwood, Blackshear, Orangeburg, St. Matthews, Fort Motte, Cameron, Sumter, Summerton, and James Island, S. C.; Durham, N. C.; and at Eastville, Va. Besides personal observations at the places above enumerated, specimens of pecans (*Carya illinoensis*) showing undoubted symptoms of rosette have been received from a much wider territory including Arizona, Tennessee, and other States. Similar symptoms have been observed by the authors upon other species of hickory, notably the mockernut (*Carya alba* (L.) K. Koch.), and the pignut (*C. glabra* (Mill.) Spach.), also upon the butternut (*Juglans cinerea* L.), the rock walnut of Texas (*Juglans rupestris* Engelm.), the hackberry (*Celtis occidentalis* L.), and the common locust (*Robinia pseudacacia L.*).

Furthermore, pecan rosette does not appear to be limited to any particular soil type, topography, or season. We have noted many distinct and undoubted cases in the deep sand of the Florida Coastal Plain with the water table at 3 to 3½ feet from the surface, farther inland in deep sand or sandy loam with the water table varying from 2 to 10 feet, in sand or sandy loam underlain by yellow, red, or white clay at depths varying from a few inches to several feet and with a varying water table, in the clay or sandy clay of washed-out hillsides, in the river bottom and alluvial soils of Louisiana and Texas, in the black upland soils of Texas, in cultivated and uncultivated land, with and without fertilization, in extremely rich and extremely poor soils, and in wet and dry seasons. In fact, for the localities personally investigated, swamp land has presented the only location so far entirely exempt. It is true that wherever the soil tends to be water-soaked through a considerable portion of the growing season the pecan presents an unhealthy appearance through its failure to make proper growth and through the sickly yellow appearance of the leaves. Under such conditions the tree usually dies sooner or later. The symptoms, however, bear so little resemblance to those of rosette that even the most casual observer will not confuse the two diseases.

SYMPTOMS AND VIRULENCE OF PECAN ROSETTE

Pecan rosette first makes itself evident through the putting out of undersized, more or less crinkled, and yellow-mottled leaves (Pl. XXIV, figs. 1 and 2), particularly at the ends of the branches. The veins tend to stand out prominently, giving a roughened appearance to the leaf blade, and the light-green or yellowish areas which give the leaf its mottled appearance occur between the veins. In these light-colored parts the tissues are thinner and less fully developed than in the normal leaf, and later in the season they frequently become dark reddish brown and dead.

In many cases the intervascular tissue here and there fails to develop at all, so that the lamina is dotted with smooth-margined holes suggesting insect perforations which have subsequently healed over (Pl. XXV). These first symptoms may occur over the whole tree at once, but often one or more branches may be affected for several months before the whole tree appears involved. At this stage the foliage as a whole often presents a rusty appearance. The diseased branches usually fail to reach their normal length, so that the leaves are clustered together on a shortened axis, giving a bunched appearance to the group which led the senior author, about 1902, to apply the term "rosette" as an appropriate name for the disease (Pl. XXVI; cf. fig. 1, rosetted shoot, with fig. 2, normal shoot). Nuts are frequently borne and carried to maturity on these branches.

In some cases the disease goes no farther. The trees may continue in this way for several seasons, or they may recover completely after showing the early symptoms for one or more years. However, in a well-defined case where the symptoms are general over the greater part of the tree, the affected branches begin to die back from the tip during the latter part of the first season or later (Pls. XXVII and XXVIII). At first brownish spots and streaks appear in the green bark, and these dead areas increase in size until the whole end of the twig or branch dies. While death appears to start in the green bark, the cambium soon becomes affected and the wood and pith are usually discolored. This dying back or "staghorn" stage is followed during the same or the following season by the development of numerous lateral shoots from dormant or adventitious buds. In young vigorous trees these first shoots of the season are usually large and succulent, and the leaves are dark green and above the normal in size. In all probability this effect is physiologically equivalent to the effect of severe pruning. Toward the middle of the season, however, the typical yellow-mottled color appears and the later-developed leaves are more or less crimped and roughened, as well as below the normal in size. Dormant axial buds of one or two series may develop into abortive shoots, and toward the end of the season clusters of short or spindling branches usually put out from adventitious or dormant buds farther back on the branches or on the main trunk. The leaves in these cases are much reduced in size and may appear as a mere skeleton with ragged edges.

This process goes on from year to year. The growth of the tree is checked, and these abnormal clusters of branches are formed only to die back each season and be followed by others. Thus a well-marked case of several years' standing presents a characteristically gnarled and forlorn appearance (Pl. XXVIII, fig. 3). Rosette in all its forms occurs in trees from seedling and budded or grafted nursery stock to trees of long-established maturity, a hundred or more feet in height, and it is one of the worst diseases known to affect pecans.

PRUNING EXPERIMENTS

If the rosette were of a parasitic nature, it seemed entirely possible that a severe pruning out of the diseased parts or at least a cutting back to the stump might entirely eliminate the disease. To test out this proposition, 10 distinctly rosetted trees in the orchard of Mr. J. B. Wight, Cairo, Ga., were severely pruned and 5 similarly diseased trees were cut off at the ground and allowed to send up sprouts from the stump. This work was done in the winter of 1902–3, and observations the following midsummer showed the new growth in all the trees to be distinctly rosetted (Pl. XXVIII, fig. 2).

In like manner three 7-year-old trees were severely cut back, or "dehorned," and five other badly diseased trees were cut back to a stub 18 inches high. This work was carried out in February, 1912, in the orchard of Mr. G. W. Saxon, Tallahassee, Fla. The following spring most of the new growth was vigorous and the leaves were dark green and normal in appearance. Toward midseason, however, the leaves began to appear yellow mottled and those most recently developed were undersized; before the end of the season every tree and nearly every shoot was badly affected with rosette.

In the summer of 1911 three badly diseased trees belonging to the Standard Pecan Co., Monticello, Fla., were cut back to the trunk. The following midsummer all the new growth was rosetted as badly as before cutting back.

Further observations have been made upon the effect of severe pruning and cutting back in orchards at Belleview, St. Augustine, Monticello, and Tallahassee, Fla.; Thomasville, Baconton, and Albany, Ga.; and at Orangeburg, S. C. In all cases the same negative results have occurred. Usually in vigorous trees the new growth appears healthy, as in the case of rosetted trees severely cut back by the disease itself; but before the end of the summer or at least by the next season the rosette again appears. The disease was in no case eliminated by pruning.

TRANSPLANTING EXPERIMENTS

In order to determine whether the cause of the disease was to be sought in the tree itself or in the soil, several transplanting and germination tests were carried out.

In December, 1902, 8 badly rosetted trees were dug up from the J. B. Wight orchard at Cairo, Ga., and healthy seedling nursery trees were immediately set in the holes. At the same time 41 nursery trees were set in vacant places where no trees of any kind had been growing for one or more years. The following August, 1 tree out of the first group and 8 out of the second were dead, probably from effects of transplanting. All the remaining trees were apparently in a normal condition.

Of the remaining 7 trees in the first group, 4 continued healthy for two seasons and were dug up. One was badly rosetted the following season, 1 showed a slight trace of the disease at two years and was dug up, and the last tree, which was normal at the time of observation in 1903, 1904, and 1912, showed a distinct case of rosette in 1913. Of the 33 remaining trees of the second group, 16 remained normal through two years, and were cut out, 5 were normal at the time of all observations, while 12 at one time or another showed distinct symptoms of rosette. It will be noted that the percentage of trees contracting the disease did not differ greatly in the two cases.

In the same orchard, during the fall and early winter of 1904–5, 35 healthy trees, comprising 11 varieties, were set in holes occupied by rosetted trees within one year. Likewise, 11 trees, comprising 7 varieties, were set after healthy trees had been removed or in places previously unoccupied. Observations in 1912 and 1913 showed 33 trees of the first group with pecan rosette and only 2 normal. Of the second group, 6 contracted rosette, while 5 were normal in appearance.

Similarly in February, 1908, 27 trees of 7 varieties were set after rosetted trees, and 4 trees of 3 varieties in vacant places or after healthy trees. Observations in 1912 and 1913 showed 24 trees of the first group to be rosetted, and 3 healthy. In the second group 2 were rosetted, while 2 were healthy.

In the winter of 1904–5, 10 rosetted nursery seedlings at Cairo, Ga., were transplanted to a part of the same field previously unoccupied by pecan or other hickory trees. Observations during October, 1905, showed 6 trees apparently normal, 3 with symptoms of rosette on the older leaves, but with the later growth normal in appearance, and 1 with traces of rosette. The following August, 9 trees appeared healthy, and 1 presented a doubtful case of rosette. In August, 1907, all 10 trees were apparently normal. In February, 1908, 2 trees which had died from unknown causes were replaced with healthy trees of the Stuart variety. The next observation, made in September, 1912, showed 6 distinct cases of rosette (including the 2 Stuart pecan trees above mentioned), 2 trees with doubtful symptoms of rosette, and 2 normal. The last note, made in August, 1913, showed 5 distinct cases of rosette, the same 2 doubtful cases, and 3 normal trees. Four of the rosetted trees were much improved in appearance over that of the preceding season.

Forty-three rosetted nursery trees at Glen St. Mary, Fla., were transplanted from the nursery row (March, 1907), where the water table was about 18 inches below the surface, to another part of the place where the soil was a loamy sand underlain by clay, with the water table at a considerable distance below the surface. Owing probably to the late spring transplanting, 18 of the trees died without putting out leaves. Of the remaining trees (October, 1907) 18 showed distinct symptoms of

rosette, 3 had doubtful traces, while 4 were normal. During the following winter part of the vacant places were filled from the nursery, making 38 trees in all. No further observations were made until the summer of 1910, at which time no traces of the disease were apparent. In August, 1912, 18 trees were normal, 12 were distinctly rosetted, while 6 showed traces of the disease. The following August, 31 trees were normal, 2 were distinctly rosetted, and 3 showed traces of the disease. Throughout the experiment the trees received no pruning, and little attention of any kind save an occasional cultivation and moderate applications of a complete commercial fertilizer.

In December, 1903, 6 nursery trees showing symptoms of rosette were taken up at Dewitt, Ga., and sent by Mr. Herbert C. White to Washington, D. C. During the latter part of November, 1904, a like number of rosetted nursery trees were sent by Mr. J. B. Wight from Cairo, Ga. Upon receipt these trees were potted in garden soil and placed in one of the greenhouses of the Department of Agriculture. All the trees lived, but observations up to January, 1907, gave no evidence of rosette in any of them. At this time 4 were set out at Takoma Park, D. C., 4 at Glen St. Mary, Fla., along with the trees described in the preceding experiment, and the remaining 4 were left in the greenhouse. The Takoma Park trees died from other causes after the second winter, but showed no more rosette. The 4 trees set at Glen St. Mary, Fla., were healthy during 1910 and 1911. In August, 1912, 1 tree showed a trace of rosette, but the following season all 4 were healthy. The greenhouse trees remained healthy until destroyed the next year to close the experiment.

In the winter of 1912, 5 Stuart nursery trees which had reached the staghorn stage of rosette were sent by Mr. H. K. Miller from Monticello, Fla., to Washington, D. C., where they were potted in garden soil and placed in one of the Department greenhouses. The trees were rather large for potting, and therefore both roots and tops were severely pruned. Probably as a result of this severe treatment, together with the almost entire absence of lateral roots, the tops of all 5 trees died, but the following season 3 sent up sprouts from the crown. These shoots have made a perfectly normal growth for three seasons and have at no time shown the faintest traces of rosette.

In 1910 a badly rosetted Stuart pecan tree in the orchard of Dr. R. B. Garnett, at St. Augustine, Fla., was taken up by the owner and reset in another part of the place. The following winter 5 badly diseased young orchard trees were taken up and reset about a quarter of a mile distant. Observation by the junior author in August, 1912, showed the Stuart tree to be entirely recovered. Three out of the second group were entirely normal in appearance, while two still had symptoms of the disease.

It will be noted from the results of these experiments in transplanting that of the healthy trees set after rosetted trees nearly all subsequently contracted the disease, while of those set after healthy trees only about half subsequently showed symptoms of the disease. This would point toward the conclusion that some relation exists between pecan rosette and the soil, either directly through the soil itself or through its previous infection by rosetted trees.

Furthermore, it has been shown that of rosetted trees set after healthy trees in the same locality or replanted in entirely different situations, a very high percentage of the trees and often all recovered. This would tend to indicate that the soil relation is the direct cause of rosette rather than infection of the soil with parasitic organisms from previously diseased trees.

Top soil and subsoil were taken separately in March, 1913, from the immediate vicinity of trees in the last stages of rosette at Belleview and at Tallahassee, Fla. This soil was shipped to Washington D. C., and in early June, 17 normal, recently germinated pecan seedlings were set in each of the four soil types. At the same time a like number of seedlings were set in the garden soil ordinarily used in the Department greenhouses. In both cases the top soil was a sandy loam. The Belleview subsoil was almost clear sand, while the Tallahassee subsoil was a pasty red clay. Observations were frequently made throughout two seasons, but no symptoms of rosette appeared in any case. Of course, a test of this kind with a small quantity of soil in a porous 8-inch pot must be rather inconclusive with reference to any effect of the chemical ingredients of the soil, but it was thought that if the rosettte were caused by any organisms living in the soil surely there would be a chance of at least some of the trees contracting the disease. Even from this point of view two seasons under observation are not sufficient, but taken in connection with the other rosette work the evidence at this stage of the experiment is perhaps worthy of record as tending to indicate the non-parasitic nature of the disease.

GERMINATION OF NUTS

In order to determine the communicability of the rosette, pecan nuts matured in the fall of 1912 on rosetted trees were planted in moist sand in one of the Department greenhouses in Washington, D. C. As they came up they were potted in garden soil and kept under observation during the spring, summer, and fall of 1913, and the summer of 1914. The nuts were obtained under the following conditions:

Of 12 nuts obtained directly from a rosetted branch, 9 germinated. Of 10 from a tree, most of which showed rosette, 9 germinated. Both lots were from the seedling orchard of Dr. W. P. Williams, Blackshear, Ga.

Of 93 nuts from a Frotscher pecan tree, showing rosette over the whole top, 52 germinated. This lot was sent by Mr. C. A. Reed, of the Bureau of Plant Industry, from the Parker orchard, Thomasville, Ga.

Of 25 nuts obtained from rosetted branches of Teche, Alley, Stuart, and Van Deman pecans from the orchard of Mr. W. P. Bullard at Albany, Ga., 18 germinated.

Of 4 nuts from a rosetted branch on an old seedling tree at Marion Farms, near Ocala, Fla., 3 germinated.

Of a second lot of nuts from Blackshear, Ga., number unknown, taken from a rosetted tree but not from a distinctly diseased branch, 28 germinated.

Out of all the nuts which germinated not a single seedling showed any symptoms of rosette, so that whatever the cause of the disease, it is apparently not transmissible through the seed.

ISOLATION OF MICROORGANISMS AND INOCULATIONS

To further test the communicability of the disease, several healthy nursery trees at Cairo, Ga., were inoculated with pieces of tissue from a badly diseased branch in August, 1902. The bark was removed from the latter, and bits of the wood scraped up with a sterile scalpel were placed in sterile water. Incisions were then made near the terminal buds of vigorous, healthy branches and bits of the diseased material inserted. This experiment was duplicated in August, 1906, when slices of diseased buds were inserted into the terminal branches of 11 nursery trees. The inoculated trees in both cases remained healthy.

During the fall of 1911 a series of attempts was made to isolate any organisms that might be present in various parts of diseased trees. Numerous Petri-dish cultures were made from the inner bark, cambium, wood, and pith of living rosetted twigs and from the pith and inner bark of the living roots ¼ inch to 3 inches in diameter. Pieces of the tissue in each case were transferred to beef agar and corn-meal agar. All these cultures remained sterile. Material for these and the following tests was obtained by the junior author from three orchards at Tallahassee, Fla., and from specimens received from Sacaton, Ariz.

With the partly dying tissues, however, many of the cultures gave bacteria and fungi. This was to be expected, since, as is well known, large numbers of saprophytic forms soon obtain entrance to tissues which have died from almost any cause. This is particularly true of tissues which have died from physiological causes, since they are not already infested with fungous or bacterial growth.

Out of 55 pieces of pith tissue from partly dying twigs, 39 remained sterile, 12 gave colonies of fungi, including an Aspergillus, a Penicillium, and a nonfruiting whitish fungus, and 4 gave as many different types of bacteria.

Out of 22 pieces of tissue taken at the juncture of dead and living wood on badly rosetted twigs, all developed fungous colonies.

Of 40 bits of inner bark taken from dying twigs, 27 were sterile, 6 developed fungous colonies, and 7 grew bacterial colonies.

Of 32 pieces of the inner bark taken from partly dying roots, 25 remained sterile, while 7 developed colonies of bacteria.

Since no constant form appeared in the cases where organisms did develop, it was thought highly improbable that the disease could be attributed to any of them, especially since a majority of the cultures remained sterile. Nevertheless, for the sake of completeness, greenhouse inoculations were made with all the different strains isolated, including 15 types of fungus and 17 types of bacteria. In each case needle-puncture inoculations were made in the tender growing tip and in the older bark of one or more pecan seedlings, and the latter were left under bell jars for several days. Check trees were similarly punctured with a sterile needle. Daily observations were made, and at the end of a week the needle punctures in the checks, and with two exceptions in all the inoculated trees, were healing over. The tips of these two inoculated trees were beginning to wither, but since their tissues were much broken up in the process of inoculation, this was thought to be due to mechanical injury. However, for further certainty several other trees were inoculated with these two bacterial strains, care being taken to injure the succulent tissues as little as possible. These all healed over without signs of infection.

Several examinations of healthy and rosetted roots showed a whitish, fungous weft on the young roots of healthy trees which was at first not found on those with rosette. It was thought possible that the pecan might be dependent on some mycorrhizal relation for its well-being and that the absence of the fungous symbiont gave rise to the diseased condition. However, diseased and healthy trees have been dug up in Texas, Georgia, Florida, and South Carolina, and in some cases the sterile, fungous weft has been found on healthy roots, sometimes on rosetted roots, but more frequently, so far as could be detected, it was absent. Moreover, of 300 healthy trees grown from seed in the Department greenhouses at Washington, D. C., those with and without fungous weft on the roots were about equal in number. Twelve isolations were made from specimens with this fungous growth, and all, when grown on corn-meal agar, developed typical Fusarium spores.

It is by no means demonstrated that rosette has no mycorrhizal relations, but the preponderance of evidence lies strongly on the positive side of the question. The apparent absence of fungi and bacteria from still living rosetted material, as shown by cultural tests, and the negative results of inoculations with organisms obtained from partly dead rosetted material strongly support the view that the disease is not of parasitic nature.

BUDDING AND GRAFTING EXPERIMENTS

NORMAL BUDS AND CIONS ON ROSETTED STOCKS

Four badly rosetted trees in the J. B. Wight orchard at Cairo, Ga., were budded from healthy Frotscher pecan trees in April, 1903. All lived and showed rosette the following season.

Eighteen rosetted trees in the orchard of Mr. G. W. Saxon, at Tallahassee, Fla., were cleft-grafted with normal cions from an old seedling tree in February, 1912. Most of the cions began to put out leaves in the spring, but all except three were destroyed by bud worms. These three put on a vigorous and apparently healthy growth the first part of the season, but toward fall and during the following summer symptoms of rosette were distinct in all three cases.

In an orchard of the Standard Pecan Co., at Monticello, Fla., two badly rosetted trees of each variety—Schley, Stuart, and Pabst—were budded with several buds from a healthy tree. Observations the following August showed two buds on each of the Schley pecans living, four and six buds on the two Stuart trees, and one bud on one of the Pabst trees. All shoots from these buds were badly rosetted.

ROSETTED BUDS AND CIONS ON NORMAL STOCK

In the spring of 1903, 24 buds subtended by distinctly rosetted leaves were put into healthy nursery trees, and 24 similar buds into healthy orchard trees of Mr. J. B. Wight, Cairo, Ga. Observations in midsummer, 1904, showed 13 living buds in the nursery, and of these 1 had a distinct case of rosette, 1 a trace, while the others were normal. Of the buds put into the orchard trees, 20 were living and only 1 had rosette. In the latter case the tree had developed rosette over the whole top subsequent to the budding operation. This being the only one behaving in this manner it can hardly be considered probable that the rosette in this case was transmitted through the bud.

One hundred buds from rosetted branches were worked on nursery seedlings at the same place in August, 1906. A large percentage lived, and in the following midsummer no traces of rosette could be found on any of them, though the trees from which the buds were taken still showed the disease.

In August, 1907, 82 more buds were inserted on healthy seedling stocks in the same nursery. Observations the following season (October, 1908) showed the same results as in the last experiment.

Twenty to thirty rosetted buds of each of the Schley, Pabst, and Stuart varieties were worked on nursery seedlings belonging to the Standard Pecan Co., Monticello, Fla., in August, 1912. In the following August, out of the 12 living Schley pecan buds 1 showed a doubtful trace of rosette; of the 10 living Pabst buds 1 showed a distinct and 1 a doubtful trace; and of the 10 living Stuart buds 1 showed a distinct

and 1 a doubtful trace of rosette. Counts in the two adjacent nursery rows on either side showed at least as high a percentage of rosette as those worked with diseased buds.

Buds from badly rosetted branches were taken from Tallahassee, Fla., and were worked on 8 healthy orchard trees at Glen St. Mary, Fla., in August, 1912. At the same time healthy buds were inserted in branches of 2 trees with distinct symptoms of rosette. Out of 30 to 35 diseased buds inserted, 14 developed, and the following August no rosette could be found on any of them. Of the 12 healthy buds on rosetted stock, 4 had lived. In the case of 1 bud the shoot was perfectly normal, but the tree as a whole had meanwhile recovered from rosette. The 3 others showed only traces of rosette, but the tree on which they were worked also had nearly recovered from the disease.

Grafting was also attempted in this connection at Washington, D. C. Sixty 1-year-old seedlings were grafted by the veneer method with rosetted cions from Cairo, Ga., but none of the cions developed.

In February, 1912, 105 badly rosetted cions from two orchards in Tallahassee were whip-grafted into a part of the general nursery of Mr. H. K. Miller, at Monticello, Fla. Nursery trees on all sides were grafted to healthy cions. The following August 45 cions were living. Of these, 7 showed traces and 2 had developed distinct symptoms of rosette. Counts in the adjacent general nursery showed about the same percentage of rosette.

It will be noted that normal buds and cions on rosetted stocks invariably gave rosetted shoots. Rosetted buds and cions on apparently healthy stocks, with but few exceptions, gave healthy shoots, and wherever exceptions occurred the percentage of rosetted shoots was no greater than in adjacent stocks worked with normal buds. The results here tend to show that pecan rosette is not caused by a perennial mycelium, or by bacteria, or by any infecting virus within the tissues of the host.

FERTILIZER EXPERIMENTS

A fertilizer test was started in March, 1902, in a badly rosetted orchard belonging to Mr. J. B. Wight, Cairo, Ga. Alternate rows were used for the five plots, and the intervening rows in each case were left untreated. Plot 1 received nitrate of soda; plot 2, lime; plot 3, cottonseed meal, acid phosphate, and kainit; plot 4, a liberal application of stable manure; plot 5, ground bone meal. Observations in the summer of 1904 in plot 1 showed 5 trees with the same amount of rosette as at the beginning of the experiment; 1 tree, better; and 5, worse. In plot 2 there was no change in 3 trees, but 10 others were worse. In plot 3, 7 trees were in the same condition as at the beginning, 1 was better, and 3 were worse. In plot 4, 9 trees were the same, 1 was better, and 3 were worse. In plot 5, 6 trees were the same, 2 were better, and 4 worse. Two check rows in the same orchard showed, respectively, 6 trees in the same condition, 1

better, and 6 worse; and 3 the same, 2 better, and 7 worse, showing that during the years in question a slight increase in the disease had taken place, and any effect of the fertilizers applied was scarcely discernible. The plot treated with lime stands out somewhat from the rest, since there was distinctly more increase in the disease here and no tree showed signs of recovery.

In April, 1911, a 16-plot fertilizer test was started among nonrosetted 8-year-old Georgia Giant and Nelson pecans in an orchard at Baconton, Ga., at that time the property of Mr. Chas. M. Barnwell. The soil is a sandy loam underlain at 1½ to 2 feet by red clay. Two rows of each variety were taken through the block, giving 4 trees of each variety to a plot. The same general scheme of fertilizer combinations was used as that employed by Mr. M. B. Waite in his apple-nutrition experiments, and annual applications were made, except in the case of lime, which was used only at the beginning of the experiment. The land was cropped to winter oats, followed by cowpeas, the first two seasons, and the third season velvet beans only were grown in the centers. At the last observation there was but little apparent difference among the fertilized trees in general vigor and length of growth, color of foliage, and quantity of nuts, but the two check plots bore foliage of a conspicuously paler color. The condition of the various plots in August, 1913, is shown in Table I.

TABLE I.—*Summary of results from a fertilizer test with pecan trees at Baconton, Ga.*

Plot No.	Fertilizer.[a]	Number of trees with rosette.	Number of doubtful cases.	Number of healthy trees.	Average increase in diameter.
					Inches.
1	Lime	1	.....	7	1.23
2	Lime and nitrate af soda	3	2	3	.99
3	Lime and cotton-seed meal	.....	.....	8	1.25
4	Lime and muriate of potash	1	.....	6	.97
5	Lime and sulphate of potash	.....	2	6	1.29
6	Lime and acid phosphate	1	.....	6	1.27
7	Lime and Thomas phosphate	.....	.....	7	1.01
8	Lime, muriate of potash, and nitrate of soda	2	3	3	1.12
9	Lime, muriate of potash, and acid phosphate	5	.....	3	1.00
10	Lime, acid phosphate, and nitrate of soda	6	1	.....	1.33
11	Lime, muriate of potash, nitrate of soda, and acid phosphate	2	.....	6	.87
12	Muriate of potash, nitrate of soda, and acid phosphate; no lime	.....	2	4	1.48
13	Muriate of potash and acid phosphate; no lime	.....	.....	8	1.08
14	Stable manure; no lime	.....	.....	8	.94
15	Stable manure and ground bone; no lime	.....	.....	8	1.05
16	Control; no lime	.....	.....	7	1.03

[a] Fertilizers were applied at the following rates: Lime (CaO, acted on jointly by air and water), 1 bushel per tree; nitrate of soda, 8 pounds; cottonseed meal, 32 pounds; muriate and sulphate of potash, 8 pounds; acid phosphate, Thomas phosphate, and ground bone, 24 pounds; stable manure, a liberal application.

It will be noted from Table I that rosette occurred on all but two of the plots receiving an application of lime. In the five unlimed plots there were only two doubtful cases of rosette and these two trees directly bordered a limed plot. Care was taken in spreading the fertilizers on the side bordering a contiguous plot not to distribute to the middle, but the lime was spread to the dividing line, and, hence, there was a chance of its affecting the adjoining unlimed plot. The largest number of cases and those showing the most advanced stages occurred on the two limed plots, Nos. 9 and 10, treated, respectively, with acid phosphate and muriate of potash and with acid phosphate and nitrate of soda. Thus, while the results of this test have so far been partly negative, they have at least tended to show that some relation exists between pecan rosette and the constituents of the soil.

A fertilizer test was started in April, 1912, in the badly rosetted part of a 7-year-old orchard belonging to Mr. G. W. Saxon, at Tallahassee, Fla. The soil here is a sandy loam underlain by a stiff red clay. Thinking that possibly the lack of proper drainage might be a factor predisposing to rosette, the subsoil around six badly diseased trees was dynamited. Three 6-foot holes were bored at 10 to 12 feet from the trees and ¼ to ½ pound of dynamite was used to each hole. Applications of sulphur flour and of copper sulphate to the soil were also tried, each at the rate of 6 pounds to the tree. With the exception of lime, which was applied at the rate of one-third of a bushel to the tree, the fertilizers were used at the rate noted for the preceding experiment. The results of this experiment are given in Table II.

TABLE II.—*Summary of results from a fertilizer test with pecan trees at Tallahassee, Fla.*

Plot No.	Fertilizer.	August, 1912.		August, 1913.		
		Number of trees with rosette.	Number of normal trees.	Number of trees with rosette.	Number of doubtful cases.[a]	Number of normal trees.
1	Lime, muriate of potash, nitrate of soda, and acid phosphate	9	1	9	[b] 1	.....
2	Muriate of potash	3	.....	3	.....	.....
3	Acid phosphate	4	.....	3	[b] 1	.....
4	Control, subsoil dynamited	6	.....	6	.....	.....
5	Control, untreated	7	.....	6	[b] 1	.....
6	Nitrate of soda	5	.....	3	[b] 2	.....
7	Muriate of potash	5	.....	4	[b] 1	.....
8	Acid phosphate and nitrate of soda	3	.....	3	.....	.....
9	Muriate of potash, nitrate of soda, acid phosphate	6	.....	6	.....	.....
10	Stable manure	1	3	2	1	1
11	Thomas phosphate	2	1	2	.....	1
12	Lime	.....	2	1	.....	1
13	Cottonseed meal	2	1	3	.....	.....
14	Copper sulphate	1	1	1	.....	1
15	Sulphur flour	1	1	1	.....	1

[a] As these trees were badly affected with rosette at the beginning of the experiments, it is probable that their death was at least in large measure due to this disease.
[b] Dead.

As will be observed from the data given, the results were largely negative. There were no signs of recovery, and in the case of stable manure (plot 10), lime (plot 12), and cottonseed meal (plot 13), there was an increase in the number of rosetted trees. It should be noted that most of the trees having rosette at the start were well-advanced cases.

At the same time, the subsoil was dynamited around three 15-year-old rosetted trees in the orchard of Mr. G. G. Gibbs. The results in this case were likewise negative as shown by observations after one and two years. The results of dynamiting the subsoil in these two orchards, together with observations showing the absence of pecan rosette in swampy land, seem to indicate that the disease is not due directly to lack of proper subsoil drainage.

The soil around two rosetted trees in the J. B. Wight orchard, Cairo, Ga., in the spring of 1907, was treated with copper sulphate and magnesium sulphate at the rate of 1 pound of each for every inch in diameter of the trunk. The trees were decidedly injured by this treatment, and the diseased condition continued as before. A negative result followed the use of 8 pounds of copper sulphate around a single 9-year-old rosetted tree at Baconton, Ga.

The soil around each of 22 rosetted trees in the 4-year-old Davenport orchard at Belleview, Fla., was treated in June, 1912, with 2 to 4 pounds of copper sulphate, according to the size of the tree. By the following midsummer 7 trees had recovered, 7 were somewhat improved in appearance, and 8 were either in the same or in a worse condition than at the beginning. In the same 40-acre block, 117 out of 389 rosetted trees had recovered in the same period. In other words 31 per cent of the trees treated with copper sulphate recovered and also 30 per cent of the untreated trees in the same block. A considerable number of the untreated trees were also improved in appearance. Both groups of trees were fertilized by the owner with a complete commercial fertilizer at the rate of 8 pounds to the tree.

The copper-sulphate treatment has from time to time been recommended by a number of orchardists, and in a few cases observed by the junior author some apparently beneficial results have occurred. But the usual failure of the grower to run proper checks with an experiment, together with the fluctuation of the disease without any treatment, lends a rather doubtful character to the results. At any rate, this treatment is not to be recommended, except in an experimental way, until further tested out.

SPRAYING EXPERIMENT

Five rosetted trees in the J. B. Wight orchard at Cairo, Ga., were given three applications of Bordeaux mixture—in March, April, and May, 1903. No positive results from this experiment were discernible.

ORCHARD RECORDS

Rosette records for periods varying from 2 to 12 years have been kept in several orchards in Georgia, Florida, and South Carolina.

Of 159 trees observed in the J. B. Wight orchard for three successive seasons (1902 to 1904), 24 were healthy for all three seasons, 17 were healthy at the beginning, but later contracted the disease, 13 had rosette, but recovered, 108 were rosetted throughout the period, and 7 fluctuated each season.

Eighty trees in the same orchard were observed in 1902, 1903, 1904, 1912, and 1913. So far as these observations go, 30 trees remained normal throughout the period, 7 were normal, but contracted the rosette, 12 were rosetted, but recovered, 8 were rosetted throughout, and 21 fluctuated back and forth between the normal and rosetted condition.

Observations on 274 trees in the same orchard during 1912 showed 136 trees with the rosette, and during the following season 35 trees more had contracted the disease. The cultivation and fertilization had not been varied.

In a 40-acre block of the Davenport orchard at Belleview, Fla., containing 1,069 trees, 389 had the rosette in 1912 and 256 in 1913. All had received the same treatment, except for the few trees used in the copper-sulphate test, and as previously noted this treatment gave negative results. Of the three varieties present, 19 per cent of the Van Deman, 25 per cent of the Stuart, and 28 per cent of the Teche pecans had rosette in 1912.

Sixty-two soil borings were made to 6 and 9 feet from the surface and in the vicinity of both healthy and rosetted trees. Of 31 trees in a clay to sandy-clay subsoil, 13 had the rosette and 18 were normal. Of 23 trees in a sandy subsoil, 9 were rosetted and 14 were normal. Of 8 trees in a subsoil containing considerable quantities of a soft lime rock, all were healthy. In the first two groups the difference in the number of diseased and healthy trees was not conspicuous. On account of the entire absence of rosette in the third group, partial analyses of the subsoil around three trees were made. In sample No. 1 the percentages of lime, magnesium, and phosphorus, computed as the oxids, were 9.68, 0.82, and 8.32, respectively; in sample No. 2, 5.42, 1.09, and 6.03; and in sample No. 3, 0.58, 0.99, and 3.44. More or less clay was present in all the samples, and in No. 2 there was a considerable admixture of creolin.

In a small orchard of 96 trees belonging to Mr. G. G. Gibbs, at Tallahassee, Fla., 38 trees were rosetted in 1912, and during the following season 4 of these recovered. In another orchard of 116 trees on the same farm, with similar topography and apparently similar soil, 6 were rosetted in 1912 and 12 the following season.

In the G. W. Saxon orchard of 231 trees at Tallahassee, Fla., 125 trees had rosette in 1912 and 173 in 1913. Most of the orchard had received

no fertilizer for several seasons, and where fertilizer had been applied no distinct difference in the rosette could be detected.

In the W. P. Bullard orchard near Albany, Ga., 291 out of 646 trees were rosetted in 1912. By the following season 101 more trees had contracted the disease. Fertilization and cultivation were uniform for the two seasons.

In a block of 233 trees belonging to Mr. H. K. Miller, at Monticello, Fla., 81 trees had the rosette during 1912 and 1913. Fertilization was uniform for both years, and the soil was a sandy loam underlain by a rather stiff, red, sandy clay.

Observations were taken during 1912 and 1913 in three blocks belonging to the Standard Pecan Co., at Monticello, Fla. Out of 406 trees observed in the first block 231 had rosette in 1912 and 254 in 1913. In the second block of 450 trees 119 were rosetted at the first observation and 121 at the second. In the third block of 570 trees, 42 were rosetted in 1912, and 34 in 1913. A part of all three blocks were in swamp land that had not been fully drained, and the absence of rosette here was conspicuous. The soil in the remainder of the three blocks was a sandy loam underlain by a red clay or sandy clay. For three seasons preceding 1912 a complete commercial fertilizer was used. In 1912 a small application of stable manure was made around each tree.

In the small orchard of 100 trees belonging to Dr. R. B. Garnett, at St. Augustine, Fla., 3 were rosetted, both in 1912 and 1913, 7 were rosetted but recovered during the second year, and 6 new cases developed during the second year. The soil is a sandy loam underlain by a clear-sand subsoil, with the water table 3 to 3½ feet below the surface. Fertilization was uniform over the orchard, except that the soil around the 10 trees showing rosette in 1912 was treated with lime and copper sulphate. Seven of these trees recovered, but no checks were run to verify the result.

In a block of 371 trees belonging to Mr. M. O. Dantzler, at Orangeburg, S. C., 146 trees had rosette in 1912 and 137 in 1913. Fertilization and cultivation were uniform during the two seasons.

It is evident from these records that rosette fluctuates from year to year without any variation in the treatment given by the grower and that diseased trees may apparently make a complete recovery and remain healthy for an indefinite period, or after a season or two they may again contract the disease. It should be stated here that in the majority of cases the trees recovering from rosette had not reached the staghorn stage. However, a considerable number of trees with terminals dying back from the disease have been seen to recover and remain normal through the one or more seasons they have been subsequently under observation by the authors. From the variations in rosette recorded from year to year under uniform cultivation and fertilization it seems

highly probable that seasonal climatic changes, such as variation in the water content of the soil, may have at least an indirect relation to the prevalence of the disease.

ASH ANALYSES [1]

Complete ash analyses were made of rosetted and healthy leaves and of rosetted and healthy twigs from Cairo and Dewitt, Ga., and from Belleview, Fla. In each case the diseased and healthy material was from trees of the same age and variety and had received similar cultivation and fertilization in the same orchard. The pure-ash analyses are given in Tables III to V.

TABLE III.—*Ash analyses of leaves and twigs of the Stuart pecan from Cairo, Ga., September, 1912*

Constituent.	Leaves.		Twigs.	
	Rosetted.	Normal.	Rosetted.	Normal.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Total percentage of pure ash	5.59	5.02	5.47	5.49
SO_3	3.60	3.02	3.69	3.11
P_2O_5	15.47	21.11	12.26	16.59
Cl	.33	.17	.26	.14
K_2O	23.36	18.35	23.01	16.01
Na_2O	.98	.83	1.18	1.02
CaO	31.48	34.09	34.14	48.19
MgO	21.50	14.09	24.45	14.78
SiO_2	3.25	8.33	.96	1.24
Total	100.04	100.09	100.04	101.18

TABLE IV.—*Ash analyses of leaves and twigs of the Van Deman pecan from Belleview, Fla., September, 1913*

Constituent.	Leaves.		Stems.	
	Rosetted.	Normal.	Rosetted.	Normal.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Total percentage of pure ash	4.68	4.61	3.68	3.37
SO_3	7.31	5.68	6.19	4.69
P_2O_5	7.57	8.86	8.24	12.24
Cl	.38	.35	.30	.40
K_2O	18.76	16.03	21.35	25.61
Na_2O	.38	.34	2.23	3.24
CaO	37.75	32.45	44.16	36.56
MgO	20.66	20.30	17.40	16.71
Fl_2O_3, Al_2O_3	1.90	.65	Trace.	Trace.
Mn_3O_4	.40	.58	.23	.26
SiO_2	4.83	14.30	.26	.29
Total	99.94	.....	98.36	.....

[1] The ash analyses here given were made by the Bureau of Chemistry, Department of Agriculture.

TABLE V.—*Ash analyses of leaves and twigs of the Schley pecan from Putney, Ga., September, 1913*

Constituent.	Leaves.		Stems.	
	Rosetted.	Normal.	Rosetted.	Normal.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Total percentage of pure ash	4.72	4.78	2.16	2.18
SO_3	6.76	5.83	6.49	5.11
P_2O_5	6.23	6.52	6.40	7.28
Cl	.69	.26	.38	.32
K_2O	23.03	14.12	22.37	19.03
Na_2O	.49	.34	2.82	2.51
CaO	35.12	42.04	40.04	42.27
MgO	16.74	16.42	16.95	19.23
Fe_2O_3, Al_2O_3	3.03	4.84	1.43	2.23
Mn_3O_4	1.19	2.44	.61	1.09
SiO_2	6.45	7.23	1.76	.74
Total	104.45	104.82	101.41	101.99

Most of the differences between the pure ash of healthy and of rosetted material were not constant in the three sets analyzed. In both leaves and twigs from Cairo, Ga., the magnesium content was much higher in the diseased material, but in the two other sets the percentage was nearly the same in both diseased and healthy material.

The percentage of phosphorus was greater in the normal leaves of two sets and in the normal twigs of one set. In the other cases the percentage was about the same in both healthy and diseased material.

The calcium content was greater in the normal leaves and twigs of two sets and considerably less in the remaining set of material.

The percentage of potassium was greater in all the rosetted material, with the exception of one set of rosetted and normal twigs, where there was slightly more potassium in the normal.

Other differences shown by the analyses are either slight or greatly variable.

DISCUSSION OF RESULTS

PARASITISM VERSUS NONPARASITISM

The following experimental data have a bearing on the question of possible parasitism or upon nonparasitism.

Out of 144 nuts collected in different localities from badly rosetted branches, 91 germinated and none of the seedlings gave symptoms of the disease during the two seasons under observation. These nuts were placed in the greenhouses of the Department of Agriculture at Washington, D. C., which is far removed, both as to locality and environment, from the orchards where the nuts were obtained, but the conclusion from

this experiment nevertheless seems justifiable that whatever the cause of the disease it is not transmissible through the seed (see p. 155).

Inoculation of tender growing tips with bits of diseased tissue gave negative results. Attempts at isolation of micro-organisms from living rosetted material gave negative results in all cases. Various fungi and bacteria were isolated from partially dead material obtained in four different orchards, but no constant form appeared and inoculations gave negative results (see p. 156). These results strongly support the view that pecan rosette is not of a parasitic nature.

Mycorrhiza have been found promiscuously on both normal and rosetted trees, or perhaps more often the roots of both normal and rosetted trees have appeared to be free from any such fungous growth. It is probable that the disease is not due to the presence or absence of mycorrhiza (see p. 157).

Where normal buds or cions were worked upon rosetted stocks they have invariably developed the disease during the same or the following season, except in a few cases where the trees used as stock had in the meantime themselves recovered. With few exceptions rosetted buds and cions worked upon apparently normal nursery and orchard trees developed into normal shoots. Where rosetted shoots developed their percentage was no greater than in contiguous nursery rows or orchard trees worked to normal buds or cions (see p. 158). The results here tend to show that rosette is not caused by a perennial fungus mycelium, by bacteria, or by any infecting virus within the tissues of the pecan.

Healthy nursery trees set in large pots of top soil and of subsoil taken around badly rosetted trees remained normal during the two seasons under observation (see p. 155). This series of tests was carried out in the Department greenhouses at Washington, D. C., small quantities of the soil being used under entirely different environment than present in the location from which obtained. The results are therefore not taken as conclusive, but merely as tending to indicate the nonparasitic nature of the disease.

Transplanting of healthy nursery trees to holes from which rosetted trees had been removed gave a very high percentage of rosette in the replants, while transplanting badly rosetted trees to situations where less rosette or none at all had been observed gave a very high percentage of recovery (see p. 152). By comparison of the results of these two tests it appears that a soil relation is the important factor in causing rosette rather than any transmission of the disease from one tree to another.

Thus, from the nontransmission by seed, the negative results of isolation and inoculation tests, the varying presence and nonpresence of mycorrhiza, the budding and grafting tests, and the transplanting work, the nonparasitism of pecan rosette is considered a reasonable assumption.

RELATION TO THE SOIL

The relation of pecan rosette to the soil is partially elucidated by the following experimental data.

Severe pruning of rosetted trees or cutting back to a stump gave negative results (see p. 152). The new growth was often healthy in appearance, but toward autumn or during the following season symptoms of rosette invariably reappeared (Pl. XXVIII, fig. 2). The fact that in no case was the disease eliminated by this treatment is at least not unfavorable to the view that it is contracted directly or indirectly through the soil.

Transplanting of healthy nursery trees to holes from which rosetted trees had been removed gave a very high percentage of rosette in the replants (see p. 152). These results point toward the conclusion that some relation exists between rosette and the soil, either directly through the soil itself or through previous infection of the soil by rosetted trees.

The transplanting of badly rosetted trees to situations where less rosette or none at all has been observed gave a very high percentage of recovery (see p. 153). All rosetted trees replanted at Washington, D. C., recovered, though many of them were dying back with the disease when first taken up (see p. 154). In the latter cases the entire change of both soil and climate is held accountable for the uniform recovery of all rosetted trees. All these transplanting tests with rosetted trees tend to indicate the soil relation as the direct cause rather than infection of the soil with a parasitic organism or virus from previously diseased trees.

The results of the fertilizer experiments were partially negative (see p. 159). However, in a 16-plot test upon normal trees at Baconton, Ga., 9 out of 11 limed plots developed cases of rosette, while 1 out of 5 unlimed plots showed doubtful traces on two trees bordering a limed plot. Careful observation at the beginning of the experiment did not reveal a single case of rosette, and at the last observation no rosette was found in contiguous parts of the orchard. The plots receiving lime, acid phosphate, and nitrate of soda and those receiving lime, acid phosphate, and muriate of potash developed by far the most rosette. In fertilizer experiments at two other points considerably more rosette developed on limed than on unlimed plots. These results, while not in all cases very definite, have at least tended to show that some relation exists between rosette and the constituents of the soil and that the lime content alone or in combination with other substances may have a varying causative effect.

Dynamiting the subsoil in two different orchards gave negative results (see pp. 161–162). This fact, together with observations showing the absence of rosette in swampy land (see p. 150), seems to indicate that the disease is not directly due to lack of proper subsoil drainage.

Orchard records of individual trees over periods of 2 to 12 years show considerable fluctuations in the disease, irrespective of treatment and without any special treatment (see p. 163). Trees with a mild or moderate attack frequently recovered, and even when the staghorn stage

had been reached, trees occasionally regained their normal appearance without any artificial treatment. From the seasonal variations in rosette recorded from year to year under conditions of uniform cultivation and fertilization it seems highly probable that seasonal climatic changes, such as variation in precipitation, may have at least an indirect relation to the prevalence of the disease. In large orchards the more or less simultaneous appearance of rosette in patches, together with its usual limitation to these areas, clearly suggests some definite connection with the soil conditions.

In general, the ash analyses of rosetted and healthy material showed slight to highly variable differences, so that very little positive light was thrown upon the problem by this part of the work (see p. 165). In both leaves and twigs from one orchard the magnesium content was much higher in the rosetted than in the normal material, but in two other sets of analyses the percentage was nearly the same in both diseased and healthy material. The percentage of phosphorus was greater in the normal leaves of two sets and in the normal twigs of one set. In the other cases the percentage was about the same in both healthy and diseased material. The calcium content was greater in the normal leaves and twigs of two sets and considerably less in the remaining set. The percentage of potassium was greater in all the rosetted material, with the exception of one set of rosetted and normal twigs, where there was slightly more potassium in the normal. Other differences shown by the analyses are either slight or greatly variable.

It thus appears from the results of experiments in pruning and cutting back, transplanting tests, fertilizer experiments, results of subsoil dynamiting, and orchard records that the disease is directly or indirectly caused by some soil relation. On account of their variable character, the ash analyses shed little light on the problem.

COMPARISONS WITH OTHER DISEASES

Leaf-hopper injury suggested itself at one time as a possible cause of rosette of pecans. The rather far-reaching effects of the work of this insect were known, and the demonstration of their causal relation to curly-top of beets [1] lent further plausibility to this theory. However, extensive observations have failed to disclose any connection between this insect injury and rosette. Leaf-hopper injury has occasionally been seen on pecans, but its symptoms are distinct and it has occurred both in the presence and absence of rosette. The leaves are often yellowed around the margin, somewhat curled, and if attacked while young, their growth is considerably interfered with. But there are not the distinct yellow mottling over the whole blade between the veins, the raised appearance of the latter, and the tendency to reduction of the leaf blade, followed by the dying back of the shoot from the tip.

[1] Shaw, Harry B. The curly-top of beets. U. S. Dept. of Agr., Bur. Plant Indus., Bul. 181, 46 p., 9 fig., 9 pl. 1910.

Neither is rosette to be confused with sun scald, or "winterkill," which affects young trees especially and manifests itself in the death of the cambium at the base of the trunk. The roots are usually uninjured and healthy sprouts soon put out from the base. Again, frost injury may kill back the tips in a manner somewhat analagous to the staghorn stage of rosette, but here the foliage symptoms are lacking, and in rosette the death of the branches is usually most prominent in late summer, a season far removed from frost.

Both the yellows and rosette of peach in a general way suggest pecan rosette. However, though some symptoms may be common to all three diseases, the complete clinical picture is distinct in each case. Some of the most prominent symptoms of peach yellows consist in the production of abnormally long, spindling branches in dense groups due to the putting out of normally dormant and possibly adventitious buds. Yellowing of the leaves always occurs at some time during the course of the disease; but in spite of the name "yellows," the leaves are often abnormally dark green in a case of recent attack. The pushing into growth of normally dormant buds and also possibly of adventitious buds is likewise characteristic of pecan rosette, but the axes are shortened rather than elongated as in peach yellows. In this shortening of the axes of growth the resemblance to peach rosette is seen. In the last-named disease the twigs are so much shortened that the leaves as they develop become clustered into a compact rosette. Peach trees affected with rosette usually die during the first and never survive the second season, and those suffering from yellows rarely survive more than five seasons, but rosetted pecan trees have been known to live for 15 years. Moreover, no case is on record of a recovery from peach yellows or peach rosette, while recovery from a moderate attack of pecan rosette is frequent, and not rare, even for the later stages. Furthermore, from the experiments outlined in this paper it appears that pecan rosette is not transmissible either through the seed or by budding or grafting, while the infectious nature of peach yellows and rosette is well established through experimental bud transmission to healthy trees.

A striking resemblance is to be observed between pecan rosette and ordinary chlorosis of various trees. In moderate cases of the latter disease yellowing of the leaves occurs without notable change in form or size, and the conspicuous dying back of the branches from the tip is lacking, but all gradations occur between such cases and those where the symptoms closely simulate rosette of pecans.

The spike disease of pineapples[1] bears some general resemblance to rosette of pecans both as to effect and apparent cause. The leaves of affected pineapples become contracted at the base so as to form a spike-like blade, and the color of the leaf also becomes modified. It is claimed that cottonseed meal, sulphate of ammonia, kainit, muriate of potash,

[1] Rolfs, P. H. Pineapple fertilizers. Fla. Agr. Exp. Sta. Bul. 50, p. 97-99. 1899.

and acid phosphate aggravate the disease, while nitrate of soda and sulphate of potash seem to have a beneficial effect upon diseased plants. The fertilizer tests with pecans point toward the conclusion that rosette is also a nutrition trouble.

PROBABLE NATURE OF PECAN ROSETTE

Rosette of pecans evidently belongs among the chlorotic diseases of plants grouped by Sorauer [1] into two main classes: (1) Noninheritable and noninfectious diseases due mostly to improper nutritive supply or to injurious physical conditions, and (2) inheritable and infectious diseases due probably to enzymatic disturbances. From the results of the experiments and observations outlined in this paper it seems legitimate to conclude that pecan rosette should be placed in the first class of chlorotic diseases—viz, those nontransmissible diseases caused by improper nutritive supply or injurious physical conditions.

From the definite sequence of a considerable number of symptoms in pecan rosette it would seem more probable that the disease is directly caused by one set of conditions which, however, may be indirectly influenced by other conditions such as amount of rainfall, etc., rather than that this same set of symptoms may in different localities be caused by entirely different sets of conditions. Such a statement can not be laid down as a demonstrated fact, but the general knowledge of both plant and animal pathology renders it extremely probable.

The spike disease of pineapple, to which reference has previously been made, has been rather clearly demonstrated to be caused by improper nutritive supply, and it seems rather probable that pecan rosette is of a similar nature. From its wide distribution pecan rosette is clearly not confined to any one general soil type, but it is entirely possible that in those soils subject to the disease the proper balance between two or more soil ingredients may not be maintained. For example, the effects of a lack of proper balance between lime and magnesium are fairly well known, and it is possible that some such condition as this may be responsible for rosette. Indeed, the results of our preliminary fertilizer experiments point in this direction. The lime used was a high-grade stone lime purchased in barrels, but its content of magnesium was not known. The percentage of rosette was distinctly higher in the plots treated with lime, but in the absence of an exact analysis of the lime used it can not be determined from these tests whether the injury came from the lime alone or whether magnesium played a part in causing the disease. However, the chemical analysis of subsoil from the Davenport orchard, at Belleview, Fla. (see p. 163), would seem to show that lime of itself is not injurious. In this orchard the only type of subsoil entirely free from pecan rosette gave by analysis 0.58 to 9.68 per cent of lime, 3.44 to 8.32 per cent of phosphorus, and 0.82 to 1.09 per cent of magnesium, all com-

[1] Sorauer, Paul. Handbuch der Pflanzenkrankheiten. Aufl. 3, Bd. 1, p. 308. Berlin, [1906].

puted as oxids. Lime was present as both carbonate and phosphate. It will be noted that the magnesium content was low. Considerable clay was present in all these cases and frequently with a considerable admixture of creolin.

The possibility of some relation to soil organisms is not entirely precluded, but it is thought that the direct cause will ultimately be found in some lack of balance in the nutritive supply, or possibly in some toxic organic substance or substances in the soil. The large group of physiological diseases to which pecan rosette seems to belong constitutes one of the most baffling series of problems now before the pathologist; and although a large number of workers have been investigating these diseases, none of them has as yet been fully worked out, either as to cause or control.

CONTROL

No great or constant difference in varietal resistance has been observed among the common orchard varieties. In one orchard a certain variety may have a much higher percentage of rosette than some other variety, but in another place the relative amount on the same two varieties is just as likely to be reversed. This has been shown clearly by orchard records in widely separated localities. Evidently the difference in apparent resistance in such cases is due either to a differenc in soil conditions in the two parts of the orchard or to a difference in the resistance of the stocks to the inciting cause. That there is sometimes a difference in the true resistance of the stocks seems evident from the fact that of two trees of the same variety growing side by side (1 foot to several rods apart) one may have rosette and the other appear perfectly normal. If the cause of the disease lies in the soil, as appears to be the case, such an influence of the stock would naturally be expected. There appears to be little doubt then as to the existence of a difference in the resisting power toward rosette, but orchard records and observations tend to show that this difference is usually manifested through the stock rather than through the variety worked upon it.

It should be added that until more is definitely known as to the direct cause of pecan rosette little can be said of its control by use of resistant stocks or by other methods. Good care and fertilization are to be recommended, but until more is known of the lime-magnesium balance in relation to rosette, orchardists should test the effects of lime upon a few trees before using it on a commercial scale. The use of copper sulphate upon the soil, though favored by many growers, can hardly be recommended as a remedy for rosette without more conclusive data as to its efficacy than have yet been forthcoming (see p. 162). The results of our experiments have shown that pruning as a remedial measure is of no avail. Since there is no evidence that pecan rosette is transmissible from tree to tree, the cutting out of orchard trees showing only traces of the disease is hardly to be recommended, because they

very often completely recover. However, with well-advanced cases, especially where dying back of the branches is prominent, there is so little chance for recovery that it would seem better to replant with sound, healthy, new trees, notwithstanding the fact that the unfavorable soil conditions may persist and cause a second failure.

As to the advisability of using rosetted nursery stock, no absolute statements can be made with the present state of knowledge concerning the cause of the disease and varying resistance of the stock to that cause. However, orchard and nursery records show rather clearly that a difference in resistance of stock does exist. This being granted, it is reasonable to suppose that among nonrosetted and rosetted stocks in the same nursery the latter, if ultimately set out in soils tending to cause rosette, will be far more likely to give rosetted orchard trees than the former. This theory is borne out by the fact that in one large orchard where records of the condition of the nursery stock used in planting were kept, observations after several years showed a much higher percentage of rosetted trees from the rosetted stock than from the nonrosetted stock. It is true that the rosetted stocks were set together in one part of the orchard and that some difference in soil constituents not revealed by soil borings may have caused the difference in prevalence of the disease, but this seems hardly probable.

Hitherto, pecan nurserymen have paid little attention to the presence of rosette in the nursery stock used in budding and grafting except in extreme cases of the disease, and it is thought by the authors entirely possible that part of the wide prevalence of the disease may be due to the dissemination of susceptible stock from the nurseries. The disease is a serious one on account of the fact that crop production and recovery from well-advanced stages are seldom seen, and for the good of the pecan industry in general the number of cases of rosette should be kept at a minimum. In view of these facts, the discarding of all rosetted nursery stock is to be strongly recommended.

SUMMARY

Pecan rosette has been rather generally recognized by growers as a serious disease almost from the inception of pecan orcharding. It does not appear to be limited to any particular soil type, topography, or season. The disease first makes itself evident through the putting out of undersized, more or less crinkled, and yellow-mottled leaves. The veins tend to stand out prominently, giving a roughened appearance to the leaf blade, and the lighter areas between the veins are usually not fully developed. The axes of growth are usually shortened, so that the leaves are clustered together into a sort of rosette. In well-marked cases the branches usually die back from the tip, and other shoots are developed from normal or adventitious buds, only in their turn to pass through the same series of symptoms.

The nonparasitism of the disease seems rather definitely established experimentally from the nontransmission by seed, the negative results

of isolation cultures and inoculation tests, the varying presence and non-presence of mycorrhiza on both healthy and rosetted trees, the budding and grafting tests, and the transplanting experiments.

It appears from the results of experiments in pruning and cutting back, transplanting tests, fertilizer experiments, results of subsoil dynamiting, and orchard records that the disease is directly or indirectly caused by some soil relation. On account of their variable character the ash analyses have shed but little light on the problem.

Leaf-hopper injury has been observed on pecans, but is distinct from rosette and has occurred both in the presence and the absence of the latter disease. Sun scald, or "winterkill," manifests itself in the death of the cambium at the base of the trunk and is not likely to be confused with rosette. Frost injury may simulate rosette in the killing back of the terminals, but the other rosette symptoms are lacking. Rosette and yellows of peach in a general way suggest pecan rosette, but though some symptoms may be common to all three diseases the complete clinical picture is distinct in each case. A striking resemblance is to be observed between pecan rosette and ordinary chlorosis of various trees, where all gradations occur from mere yellowing of the leaves to cases where the symptoms closely simulate rosette of pecans. The spike disease of pine-apples also bears some general resemblance to the rosette of pecans, both as to effect and apparent cause.

Observations and experimental evidence point to the conclusion that pecan rosette belongs among the chlorotic diseases of plants grouped by Sorauer into two main classes: (1) Noninheritable and noninfectious diseases, due mostly to improper nutritive supply or to injurious physical conditions, and (2) inheritable and infectious diseases, due probably to enzymatic disturbances. It seems legitimate to conclude from the data outlined in this paper that pecan rosette belongs in the first group. The evidence strongly points in the direction that the disease is caused by improper nutritive supply, and it seems probable that it is directly related to a lack of balance between two or more soil ingredients. The possibility of some relation to soil organisms is not entirely precluded, but it is thought that the direct cause will ultimately be found in some lack of balance in the nutritive supply, or possibly in some toxic organic substances in the soil.

There appears to be little doubt as to a difference in resisting power toward rosette, but orchard records and observations tend to show that this difference is usually manifested through the stock rather than through the variety worked upon it. Good care and fertilization are to be recommended, but the effects of lime should be tested upon a few trees before using it on a commercial scale. Pruning is of no avail as a remedial measure. Trees showing only traces of rosette may be left in the orchard, but all advanced cases should be cut out and replanted. On account of resistance versus susceptibility of stock, the discarding of all rosetted nursery trees is to be strongly advised.

PLATE XXIV

Fig. 1.—One normal pecan leaf and two leaves with rosette from Dewitt, Ga. Note the partial reduction of the leaf blade to the midrib.

Fig. 2.—Pecan shoot with early symptoms of rosette.

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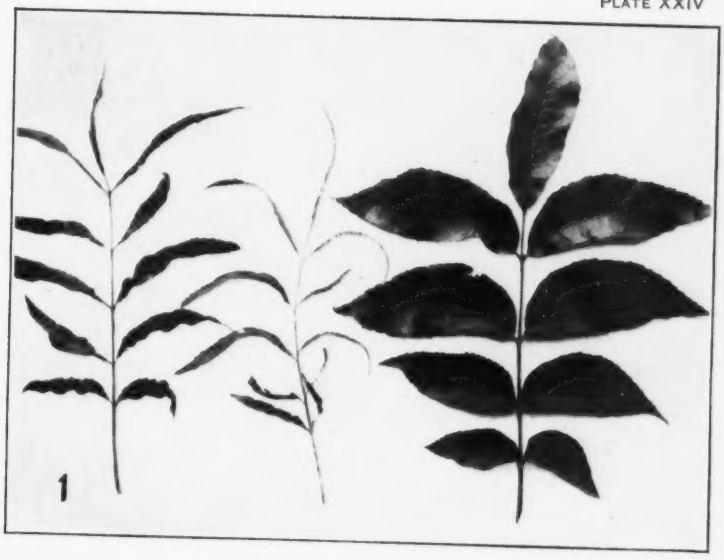
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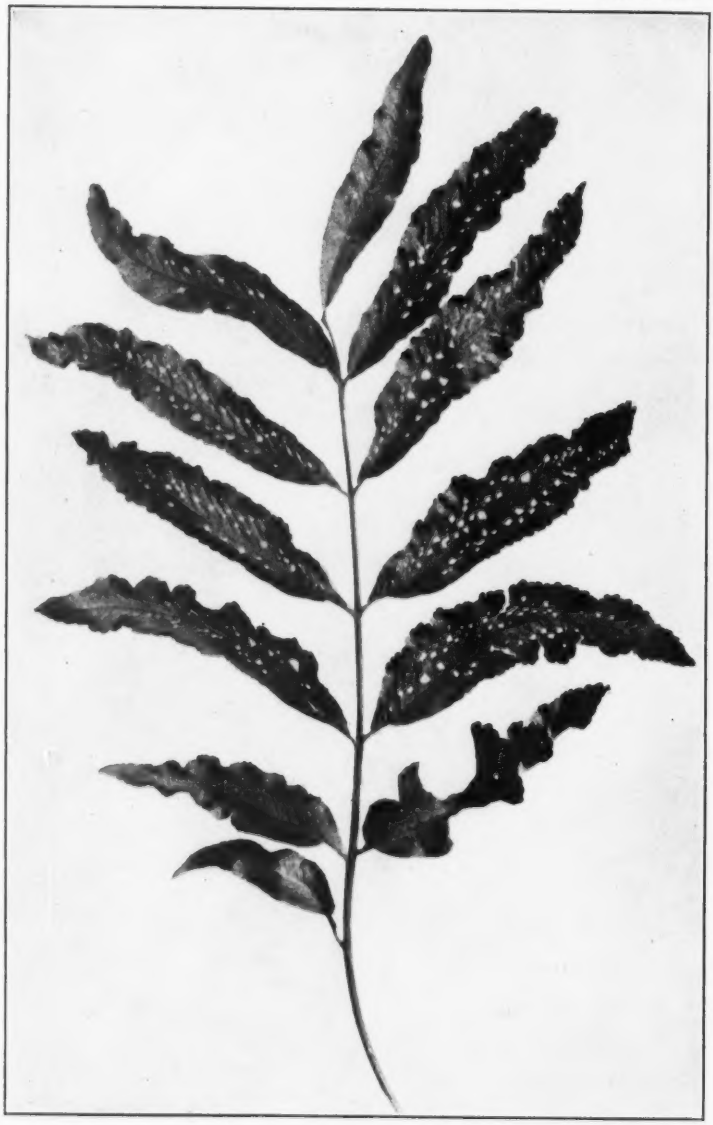

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PLATE XXV

Rosetted pecan leaf showing perforations due to the failure of part of the mesophyll to develop. About natural size. From Cairo, Ga., October, 1903.

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PLATE XXVI

Fig. 1.—Pecan shoot in advanced stages of rosette. Note the raised veins, perforations, and reductions in area of leaf blade; also dying back of terminals. From Cairo, Ga., 1903.

Fig. 2.—Normal pecan shoot for comparison with rosetted shoot. From Cairo, Ga., July, 1903.

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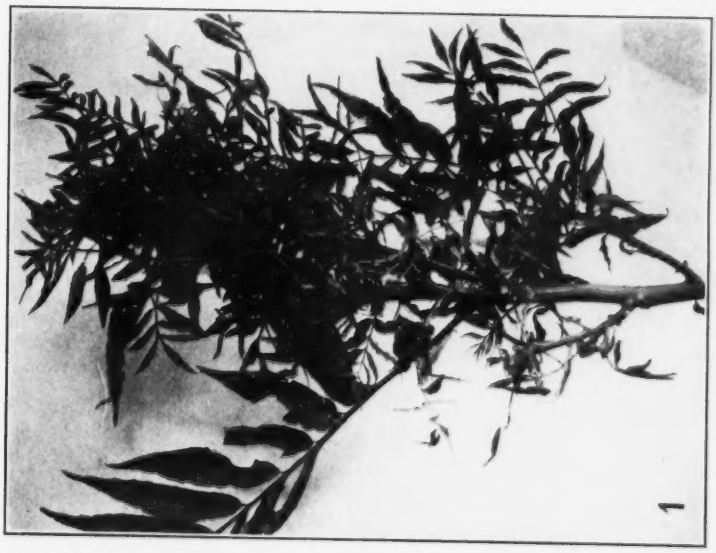
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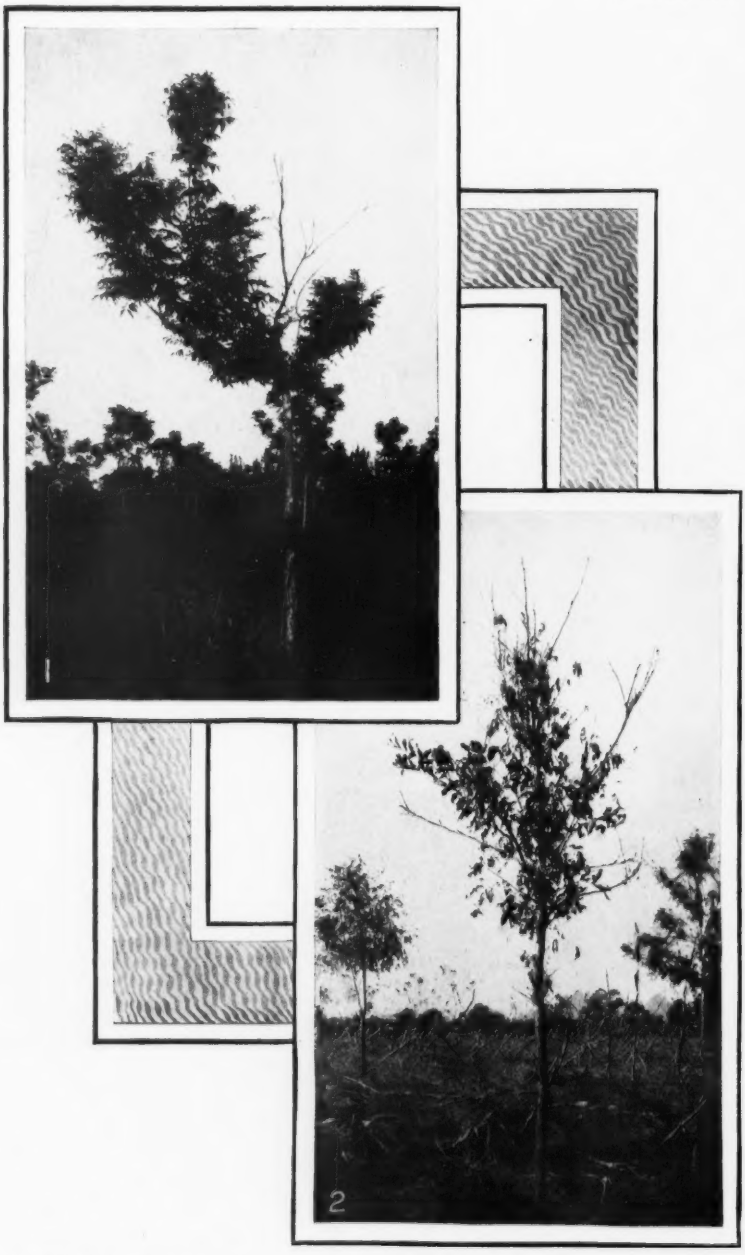

PLATE XXVII

Fig. 1.—Young orchard pecan tree with a moderate attack of rosette on the left side and seriously dying back from the disease on the other side. Note the cover crop of cowpeas. From Cairo, Ga., November, 1905.

Fig. 2.—Young orchard pecan tree in advanced stages of rosette. Orchard interplanted with corn. From Blackshear, Ga., November, 1905.

PLATE XXVIII

Fig. 1.—Young orchard tree with severe attack of rosette. Note dying back of branches. Orchard interplanted with corn. From Blackshear, Ga., November, 1904.

Fig. 2.—Rosetted pecan tree cut off to the stump the preceding season, with the present season's growth again distinctly showing rosette. From Cairo, Ga., October, 1903.

Fig. 3.—Two seedling pecan trees planted the same day from the same lot of seedlings. The tree in the background was normal, while the one in the foreground had been affected with rosette almost from the time of planting. Note the effect of a severe and long-standing case of the disease. From Tallahassee, Fla., summer of 1912.

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PRELIMINARY AND MINOR PAPERS

A NITROGENOUS SOIL CONSTITUENT: TETRACARBONIMID

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In 1913 brief mention (Shorey, 1913a)[1] was made of the isolation from a soil of a nitrogenous compound that had the properties of tetracarbonimid ($C_4H_4N_4O_4$). Since then this compound has been isolated from a number of soils and its identity as tetracarbonimid has been confirmed.

In the isolation of this compound an alkaline extract obtained by treating the soil with a 2 per cent solution of sodium hydroxid for 24 hours at room temperature was used. This extract was made acid with sulphuric acid and filtered. The acid filtrate was shaken out with ether to remove the acids and other compounds that are soluble in this solvent, and a solution of mercuric sulphate in dilute sulphuric acid was added until no further precipitate was formed. The precipitate was filtered off, well washed, suspended in water, and decomposed with hydrogen sulphid.

After the removal of mercuric sulphid by filtration, the dark-colored filtrate was concentrated to a smaller volume and excess of a solution of neutral lead acetate added. The dark-colored precipitate thus formed was removed by filtration and ammonia added to strong alkalinity. The white or cream-colored precipitate thus formed was filtered off, well washed, and decomposed by hydrogen sulphid, the lead sulphid was filtered off, and the filtrate was evaporated almost to dryness and allowed to stand. Crystals formed in this semisolid mass in a short time, and after standing a number of hours several volumes of alcohol were added and the solution was filtered. The alcoholic filtrate was concentrated to a small volume, and from this solution crystals separated in a short time. These were separated by filtration, dissolved in hot water, the solution filtered and concentrated to the crystallizing point and allowed to stand several hours, when the compound separated in a fairly pure form. By repeating this operation several times it was obtained in the form of small plates or prisms free from color.

Several points in this method as thus briefly outlined are deserving of further comment. The original acid filtrate from the humus extract is usually dark colored, and the treatment with mercuric sulphate in acid solution produces a dark-colored precipitate that removes nearly all color from the solution. When this precipitate is decomposed with hydrogen sulphid, a dark-colored solution again results from which neutral lead acetate precipitates most of the color without apparently removing the compound under discussion. This is mentioned because

[1] Bibliographic citations in parentheses refer to "Literature cited," p. 178.

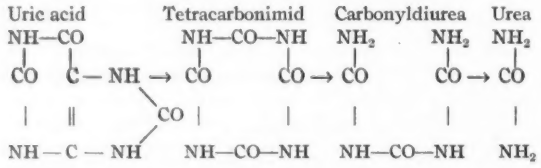
tetracarbonimid when alone and pure is precipitated by neutral lead acetate.

Further, when tetracarbonimid is pure, it is very slightly soluble in alcohol, but the presence of impurities which accompany it in this method of isolation affects its solubility in alcohol to such an extent that the first step in its purification is best effected by solution in alcohol. This treatment separates it from calcium salts and other inorganic impurities that always accompany it when precipitated from soil extracts by lead or mercury salts.

The crystals of the compound as first obtained are in the form of thin micaceous scales of rather unusual appearance, but since this changes when the compound is purified it can not be regarded as characteristic.

As thus obtained from soils, tetracarbonimid is in the form of small white prisms or plates rather difficultly soluble in cold but readily soluble in hot water. The crystals are very little soluble in alcohol, ether, or other solvents. The compound has no definite melting point, but when heated above 300° C. it decomposes, giving off acrid vapors that redden blue litmus paper, a white sublimate being deposited at the same time. An aqueous solution gives precipitates with silver, mercury, or lead salts. Barium chlorid produces no precipitate, but on the addition of barium chlorid and sodium hydroxid it is completely thrown down as a voluminous white precipitate.

Tetracarbonimid ($C_4H_4N_4O_4$) was first obtained by Scholtz (1901) by oxidizing uric acid in alkaline solution with hydrogen peroxid. The work of Scholtz was confirmed in 1909 by Schittenhelm and Wiener (1909), who by modifying the conditions of oxidation obtained another compound, carbonyldiurea ($C_3H_6N_4O_3$). These authors suggested that tetracarbonimid and carbonyldiurea might be intermediate steps in the oxidation of uric acid to urea in the human body, as shown below.



Tetracarbonimid was prepared from uric acid according to the method of Scholtz and its properties compared with the compound obtained from the soil. The two preparations were found to be identical in crystalline form and solubility, in being precipitated from solution by metallic salts, and in their behavior on heating. Their identity was further confirmed by the analysis of the barium salt and the determination of the nitrogen content.

The preparation from the soil was found on analysis to contain the following percentage of nitrogen: Sample No. 1, 32.59 per cent, and sample No. 2, 32.47 per cent of nitrogen, the theoretical nitrogen content of $C_4H_4N_4O_4$ being 32.61 per cent. The barium salt prepared by precipitating a hot, saturated solution of the soil compound with barium hydroxid was found to contain 61.55 per cent of barium, the barium content of $C_4Ba_2N_4O_4$ being 62 per cent. These figures, together with the correspondence in properties, are sufficient to establish the identity of the soil compound as tetracarbonimid.

Tetracarbonimid was first obtained from a sandy soil from Florida devoted to orange culture. This soil was one of the series of 16 samples referred to in a previous paper (1914), and in which vanillin and other benzene derivatives were found. Tetracarbonimid was found in three of these soils in sufficient quantity to make its identity certain, and in six other samples crystals having, so far as could be ascertained, the same properties as tetracarbonimid, were obtained in small quantities by the same method. This compound was also found in three out of four soils from other locations than Florida which were examined for it. These soils were (1) a sample of Norfolk sandy loam from Virginia, (2) a Sassafras soil from the grounds of the Department of Agriculture, and (3) a sample of Elkton silt loam from Maryland. These results indicate that tetracarbonimid is not an uncommon or accidental soil constituent.

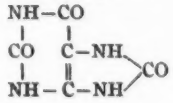
The soil from the Department grounds contained more of this compound than the others examined, and from 18 kg. of this soil 30 mg. of pure tetracarbonimid were obtained. The loss in purification in this separation was at least 50 per cent, so that, assuming that the treatment with sodium hydroxid extracted all of this compound, there was present per acre-foot of soil approximately 7 pounds of tetracarbonimid, representing 2.3 pounds of soil nitrogen. This soil had a total nitrogen content of 0.13 per cent, or approximately 5,200 pounds of nitrogen per acre-foot, and it appears that the quantity of tetracarbonimid nitrogen is at any one time but a very small part of the total.

However, in this investigation some evidence has been obtained indicating that the quantity of tetracarbonimid fluctuates under varying conditions of cultivation or crop growth. If, then, this compound is formed from other compounds under certain soil conditions and its disappearance by oxidation or other means, such as use by plants, is influenced also by conditions that vary, it may, in spite of the small quantity present at any one time, be an important step in the transformations that organic nitrogen undergoes in the soil.

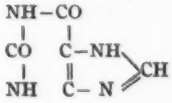
Tetracarbonimid has so far not been reported in any plant or animal tissue and has been made only by the mild oxidation of uric acid. Uric acid has not been found in soils or plants, and while it might be added to soils in human excrement, it is not a common constituent of manures or fertilizers; therefore it would seem that the source of tetracarbonimid in soils must be sought in some other compound.

The close relation of uric acid to the purin bases suggests these as possible sources of this compound, and there is no theoretical reason for assuming that any of the purin bases might not under proper conditions of oxidation yield tetracarbonimid. This possibility is disclosed more clearly by consideration of the structural formulas.

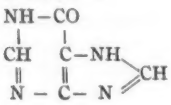
Uric acid
(2.6.8. oxypurin)



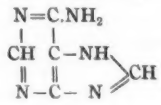
Xanthin
(2.6. oxypurin)



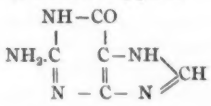
Hypoxanthin
(6 oxypurin)



Adenin
(6 amino-purin)



Guanin
(6 amino-6 oxypurin)



Xanthin, hypoxanthin (Schreiner and Shorey, 1910), and adenin (Shorey, 1913b, p. 16) have been found in soils, and guanin has been found in a soil that had been heated (Lathrop, 1912). All four bases have been found in plants and may also be formed from nucleic acid, a constituent of all nucleated cells of both plants and animals.

LITERATURE CITED

LATHROP, E. C.
1912. Guanine from a heated soil. *In* Jour. Amer. Chem. Soc., v. 34, no. 9, p. 1260–1263.

SCHITTENHELM, ALFRED, and WIENER, KARL.
1909. Carbonyldiharnstoff als Oxydationsprodukt der Harnsäure. *In* Ztschr. Physiol. Chem., Bd. 62, Heft 1, p. 100–106.

SCHOLTZ, M.
1901. Ueber ein neues Oxidationsproduct der Harnsäure. *In* Ber. Deut. Chem. Gesell., Jahrg. 34, Bd. 3, No. 17, p. 4130–4132.

SCHREINER, OSWALD, and SHOREY, E. C.
1910. Pyrimidine derivatives and purine bases in soils. *In* Jour. Biol. Chem., v. 8, no. 5, p. 385–393.

SHOREY, E. C.
1913a. Recent work on the chemical composition of humus. (Abstract.) *In* Jour. Wash. Acad. Sci., v. 3, no. 9, p. 260.
1913b. Some organic soil constituents. U. S. Dept. Agr., Bur. Soils Bul. 88, 41 p., 1 pl.
1914. The presence of some benzene derivatives in soils. *In* Jour. Agr. Research, v. 1, no. 5, p. 357–363.

APPLE ROOT BORER

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INTRODUCTION

While engaged in observations on the larval habits of the roundheaded apple-tree borer (*Saperda candida* Fab.) in West Virginia during the year 1911, the writer noticed in apple (*Malus* spp.) numerous burrows of some smaller insect associated with those of the former. Infested wood was collected and adults were reared, which were determined by Mr. E. A. Schwarz, of the Bureau of Entomology, as *Agrilus vittaticollis* Rand., a species of beetle which hitherto had not been recognized as an enemy of cultivated fruit trees. Further observations showed that the species is quite generally distributed throughout the Appalachian fruit region and that in places it is doing considerable damage to young apple trees.

The literature pertaining to this insect is meager. The species was first described from Massachusetts by J. W. Randall in 1837 and received the name which it now bears. In 1841 it was redescribed by Gory, in his monograph of the buprestids, as *Agrilus frenatus*. Le Conte, in 1857, lists the species as "*A. frenatus* Gory," with the note, "unknown to me." Again, in 1859 the same writer, in his Revision of the Buprestidae of the United States, uses both names as synonymous, giving neither the preference. In 1871 Edward Saunders in his Catalogus Buprestidarum, gives Randall's name the preference over Gory's. Since that time the species has been mentioned occasionally in lists of Buprestidae as *Agrilus vittaticollis* Rand.

E. P. Austin, in 1875, seems to have been the first to associate the insect with a host plant, at which time he notes: "Found occasionally in various parts of the State [Massachusetts] and seems to live on shadberry (*Amelanchier canadensis*)." In 1889 Frederick Blanchard, in his list of the Buprestidae of New England, records that in Massachusetts the beetle is found occasionally in June, feeding on the leaves of thorn, service, or shadbush (*Amelanchier canadensis*) and chokeberry. A specimen of the beetle in the United States National Museum was collected by W. F. Fiske in June at Tryon, N. C., on leaves of Oxydendrum. The species is also recorded from Michigan, Pennsylvania, and New Jersey, and it probably occurs throughout the greater part of the eastern United States.

At the suggestion of Prof. A. L. Quaintance, in charge of deciduous-fruit insect investigations for the Bureau of Entomology, a further study of the insect and its habits was made, the results of which are recorded below.

NATURE AND EXTENT OF INJURY

The injury to the trees is done by the slender, white larva of the insect, which bores through the sapwood and heartwood of the roots and lower trunk. The burrows through the roots frequently extend outward for

several feet and in badly infested trees are so numerous that the roots often die, causing a weakening of the whole tree.

The work of the insect is obscure, there being no chips or castings thrown to the surface, as is the case with the common roundheaded apple-tree borer. The egg, which is placed rather conspicuously on the bark of the trunk, and the exit hole in the bark through which the adult escapes from the wood, are the only external marks made by the insect on the tree. In addition to the injury resulting from the damaged roots, the exit holes in the bark admit more or less water, which frequently induces decay of the heartwood. The harm one individual root borer is capable of doing to a tree is much less than that usually done by a single roundheaded apple-tree borer, but in the localities where investigations were made the former species outnumbered the latter.

At French Creek, W. Va., 345 apple, pear, and service, or shadbush, trees, from ½ inch to 5 inches in diameter were cut off a few inches above the ground, and the burrows made by the larvæ of both species in ascending the trunks to pupate were counted. The three species of trees are favorite food plants of both of these borers, and the results of the counts, recorded in Table I, give an idea of the relative abundance of the two borers in the one locality. Similar results were obtained in several other localities where fewer trees were examined.

TABLE I.—*Relative abundance of burrows of Agrilus vittaticollis and Saperda candida in apple, pear, and service trees*

Kind of trees.	Number of trees.	Number of burrows of Agrilus.	Number of burrows of Saperda.
Apple	125	311	101
Pear	20	9	0
Service	200	342	21
Total	345	662	122

Most of the apple and pear trees cut for the foregoing counts were such seedlings as could be found in roadside fence corners and neglected orchards, and the service trees were in the woods. Only 36 of the 125 apple trees, or about 28 per cent, were free from the burrows of Agrilus and 87, or about 70 per cent, were free from burrows of Saperda.

FOOD PLANTS

The adult of this insect has been recorded by various writers as frequenting the foliage of service, wild thorn, and chokeberry. The writer has found the larva attacking apple, pear, wild thorn, wild crab, and service. It has been found rather abundantly in the following West Virginia localities: French Creek, Cherry Run, Sleepy Creek, Springfield, Moorefield, Romney, Keyser, Elkins, and Junior. Mr. E. B. Blakeslee, of the Bureau of Entomology, has found the larva in service trees at Winchester, Hayfield, and Staunton, Va. Of the several larval food plants named, apple and service seem to be greatly preferred above the others.

THE BURROWS

The burrows of the apple root borer (Pl. XXIX, figs. 1, 2, and 3) are of great length, that of a single larva often extending through the trunk and roots for 5 or 6 feet and in some cases even 8 feet. Throughout its length the burrow is packed with dustlike particles of wood that have passed through the alimentary canal of the insect. Cross sections of the burrows are oval in outline, those of full-grown larvæ being about 1 by 3 or 4 mm. in diameter.

Except for the discoloration of the dustlike packing, time does not change the appearance or form of the burrows in the wood until they are obliterated by decay. Fresh burrows are usually found within half an inch of the bark, and in large trees the position of a burrow in the wood gives some clue to its age. In the large number of old trees cut and examined during this investigation the finding of a large proportion of the burrows comparatively near to the bark is taken as an indication that this insect has been on the increase for the last 10 or 15 years.

LIFE HISTORY OF APPLE ROOT BORER

THE EGG

The eggs (Pl. XXXI, fig. 1) are somewhat variable in outline, an average specimen being flattened, oblong, disklike, 1.3 by 1.9 mm. in size. The surface is irregularly corrugated, the ridges and depressions being more distinct near the margin. When first laid, the egg is white or creamy white, but in a few days it changes to grayish brown, similar to the bark in color, and resembling in a general way the shield of a small scale insect. After the dark color is assumed, the embryo shows as a whitish spot at the center of the egg.

In the latitude of West Virginia the eggs are deposited in May and June. They are glued tightly to the bark of the trunk a few inches above the ground singly (Pl. XXX, fig. 3, *b*) or, rarely, in pairs. They are usually attached to a smooth surface, but are sometimes inserted into a crack or beneath a scale of bark. When the larva hatches, it leaves the egg from the underside and enters directly into the bark, thrusting its castings backward into the discarded shell and so filling it that it retains its normal size and shape. The abandoned shell often adheres to the bark for a year or longer.

THE LARVA

The larva (Pl. XXXI, fig. 2), before settling in the pupal chamber, is long, slender, distinctly segmented, flattened, and of nearly uniform width throughout, the first thoracic segment being slightly wider than the others. Full-grown specimens average from 3 to 4 by 30 to 36 mm. The color is white, except the small head and the anal forceps, which are brown. The anal forceps are prominent and shade from light brown at the base to dark brown or black at the converging tips. After entering the pupal cell, the larva contracts to about half its former length and in this condition (Pl. XXXI, fig. 3) it remains during the second winter of its life in the tree.

The larva lives in the tree for nearly two years, and during this time its movements are substantially as follows: On leaving the egg it bores

directly through the bark to the cambium, thence through the cambium down the trunk to the ground, whence it proceeds outward through a convenient root. After boring in this manner through the cambium for a distance of from 6 to 12 inches it burrows abruptly into the solid wood, where all the feeding throughout the remaining part of the larval stage is done. For most of its length the burrow through the cambium follows in a general way the grain of the wood. It sometimes zigzags across the grain directly after leaving the egg and invariably winds around the root in a spiral course once or twice just before leaving the cambium to enter the solid wood of the root. The burrow in the cambium soon heals and is scarcely discernible a year after it is made.

After burrowing into the solid wood of the root, the larva continues to feed outward from the tree. If the root is long enough, the burrow may continue toward the tip for a distance of 3 or 4 feet, after which it turns and is directed back toward the base. The larva spends its first winter well out from the trunk, often in a root not more than one-sixteenth of an inch in diameter. In penetrating these smaller roots it converts all the hard wood into powder during its outward and return journey. It is active late in the fall and early in the spring, and probably considerable feeding is done during the winter. With the coming of warm weather it feeds rapidly back toward the base of the root, and by midsummer it has reached the center of the root system and has begun to ascend the body of the tree. The latter part of the summer and the fall are spent in boring upward through the trunk (Pl. XXIX, fig. 2) and in fashioning a pupal chamber. In trees that are quite small pupation takes place within 5 to 10 inches of the ground, but in larger trees the larvæ for some reason ascend higher before forming the pupal cell. In apple and pear trees that are as large as 6 inches in diameter at the base of the trunk it is not unusual for the larvæ to ascend 2 or 3 feet to pupate, and in one case an individual was found in a 12-year-old pear tree that had burrowed up from the roots and pupated in a branch 46 inches above the ground.

The ascent through the trunk is usually made within half an inch of the inner bark, the larva occasionally approaching the bark but never entering it. The pupal chamber is a curved and enlarged terminus of the burrow, occupying a vertical position, with the convex side toward the heart of the tree. The upper end of the chamber curves abruptly to the bark, while at the lower end the curvature is more gradual and the chamber lacks one-sixteenth of an inch or more of extending to the bark. The two extremities are from 1 inch to 1½ inches apart, and when the chamber is completed both ends are packed with wood fragments, the insect occupying a space between.

In forming its pupal quarters the larva first extends a burrow of the usual transverse dimensions through to the bark at the upper end. It then recedes for about one-fourth of an inch and begins eating the wood from the side of the burrow. As this proceeds, the larva directs its excavation backward along the ventral side of its body and so doubles the diameter of the original gallery. The larva thus has its two ends folded closely together, and as the body moves forward the head and anus are soon contiguous. At this point the excavation ceases, and the head turns and follows the anus forward until both extremities are at the upper end of the chamber. Here the head rests, but the hinder

parts move downward until the axis of the body is again in line. At first the borer is much crumpled in accommodating itself to its restricted quarters, but a molt soon follows, after which all the segments of the body are so shortened that the space is adequate (Pl. XXX, fig. 1, *c*).

The larva does not get permanently settled in its cell until well into December, often after severe freezing weather has occurred.

THE PUPA

The pupa (Pl. XXXI, fig. 4) is broad and flattened dorsally, the males being smaller than the females. An average female measures 3.5 mm. wide by 12 mm. long. The color is white, the eyes, mouth parts, and, later, most of the abdomen and spots on the thorax changing to black as the imaginal stage is approached. The pupa occupies a vertical position in the cell, with its ventral side toward the bark (Pl. XXX, fig. 1, *b*).

Pupation takes place with the coming of the first few warm days of spring, occurring in the locality of the principal investigations from April 1 to 15. All individuals were found to have pupated in the valley of the Potomac River, near Moorefield and Springfield, W. Va., on April 20, 1912, while on the mountains a few miles distant, where the elevation was about 500 feet greater, no pupæ could be found on the same date. In Randolph County, West Virginia, at an altitude of about 2,500 feet above the sea, pupation had occurred on April 25, 1913. The pupal stage lasts from three to four weeks.

THE ADULT

The adult (Pl. XXXI, fig. 5) is a slender, elongate beetle, averaging 2.5 mm. wide by 10.5 mm. long. The elytra are black, usually with a tinge of purple; the head and thorax are iridescent purple or cupreous in some lights. The sides of the thorax and a wide stripe on top extending over the front of the head are covered with a dense bronze pubescence; the underparts are black, with a metallic purplish or coppery luster; the dorsal surface of the abdomen beneath the elytra is dark blue. A line of bronze pubescence extends along the sides of the abdomen and is visible dorsally beyond the inflected edge of the elytra. The front of the head is deeply impressed; the thorax is broader than long, its sides being regularly curved; the disk has oblique depressions on each side; the elytra are broadened behind the middle, the tips being separately rounded and finely serrulate. The upper surface is finely and densely granulate.

HABITS OF THE BEETLE

The adult apple root borers escape through small, round holes which they gnaw in the bark (Pl. XXX, fig. 3, *a*). They come forth in May, all the individuals of one generation issuing in a given locality during a comparatively short time. The beetles are active only by day, are rather quick to fly when disturbed, and have the buprestid habit of sunning themselves in exposed positions on bark and foliage.

It is probable that the life of the beetle does not often exceed two or three weeks. This is indicated by observations in the field and by experiences with a large number kept in wire cages placed over small apple trees. All beetles confined in such cages died within about two weeks.

HABITS OF OTHER MEMBERS OF THE GENUS AGRILUS

The apple root borer, *Agrilus vittaticollis*, belongs to a group that is represented by several well-known enemies of cultivated and forest plants and trees. The raspberry gouty-gall beetle (*Agrilus ruficollis* Fab.), the two-lined chestnut borer (*A. bilineatus* Weber), the bronzed birch borer (*A. anxius* Gory), and the sinuate pear borer (*A. sinuatus* Oliv.) are destructive pests whose food plants are indicated by their common names. The damage done by the different members of the genus is usually due to the larvæ working in or about the cambium, quite often of small branches or twigs. The root-feeding habit is not known to be common, although there are at least two or three other species in the Eastern States whose habits have not been fully described, the larvæ of which live in the roots of forest trees and shrubs.

NATURAL ENEMIES

So far as could be observed, the natural enemies of the apple root borer are confined to one species of hymenopterous parasite which attacks and destroys the larva and pupa (Pl. XXX, fig. 4). The adult of this parasite was first reared in April, 1912, and was described by Mr. H. L. Viereck[1] of the Bureau of Entomology, as representing a new genus, under the name *Xylophruridea agrili* (Pls. XXX, fig. 2, and XXXI, fig. 6). Two generations of this parasite occur annually, one brood of the adult appearing early in the spring and another late in the fall. Oviposition was not observed, but it is presumed that the female uses her strong external ovipositor to pierce the bark and wood, in order to get at her host. The spring brood of adult parasites oviposits on the root-borer pupæ or on the larvæ just before pupation, and the fall brood oviposits on the larvæ at about the time the pupal cell is being formed. The parasitic larvæ attack their host externally, those from the spring eggs developing rapidly, and, when full grown, constructing cocoons which occupy the host cell. This generation passes the greater part of the warm season of the year as larvæ in the cocoon. The larvæ from the fall brood of eggs develop less rapidly, some of them reaching full growth and constructing cocoons in the fall and early winter and others not entering the cocoon until very early in the spring.

The adult parasites have difficulty in escaping from their transforming quarters, and many of them die in their effort to gnaw their way out through the bark. Parasitization is much more frequent with the borers that are in very small trees. This is doubtless due to the fact that the borers in such trees are forced to work nearer the bark, where they are more constantly within reach of the ovipositor of the parasite. On the whole, from 25 to 40 per cent of the root borers are destroyed by this parasite.

REMEDIAL AND PREVENTIVE MEASURES

On account of the larva's concealed method of feeding, the digging-out process, which is used effectively against several species of fruit-tree borers, is not practicable or possible in this case. Control measures must be directed toward the protection of the trunk of the tree against the

[1] Viereck, H. L. Contributions to our knowledge of bees and ichneumon flies, including the descriptions of 21 new genera and 57 new species of ichneumon flies. Proc. U. S. Nat. Mus., v. 42, p. 646. 1912.

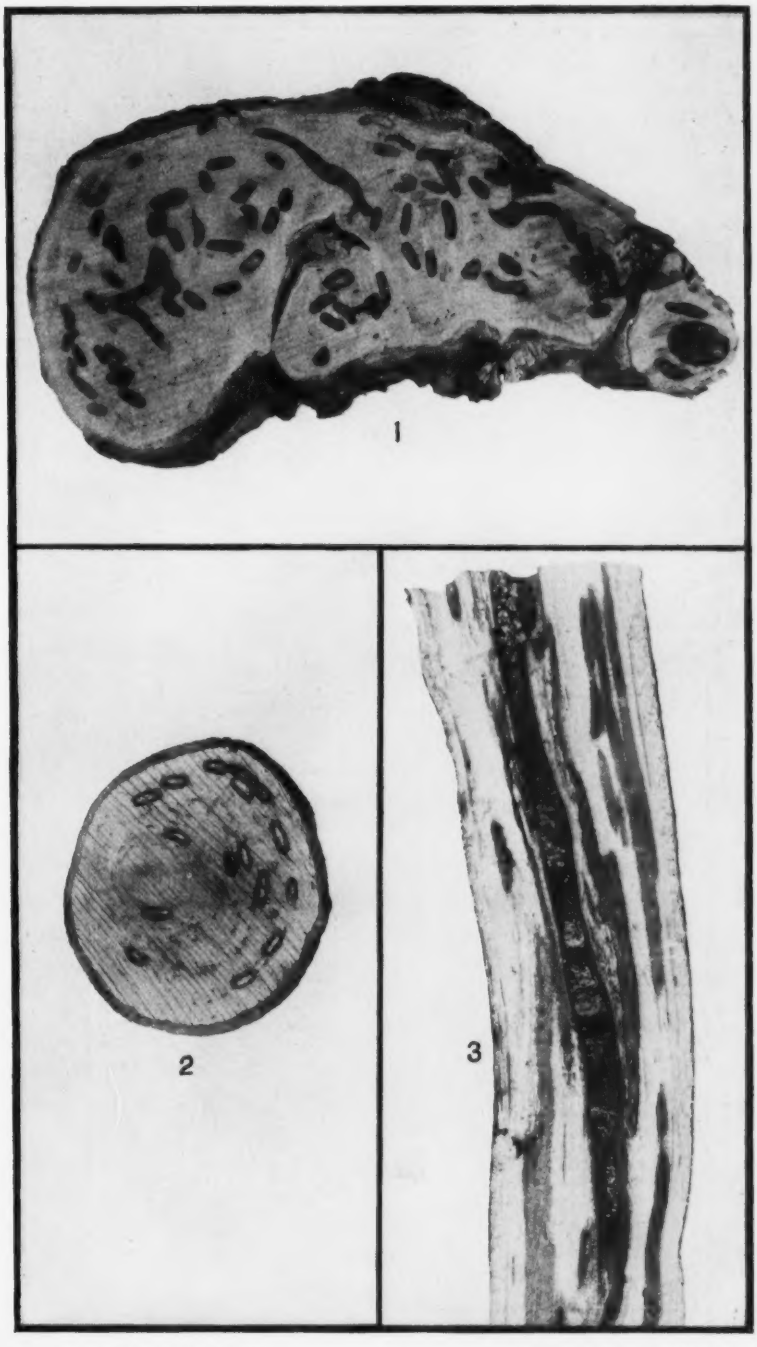
deposition of the egg rather than the killing of the borer after it begins feeding. Where paints, washes, or mechanical devices of any kind are used on trees as a preventive of injury by the roundheaded apple tree borer, equal protection may be had against the apple root borer by treating the trunks at about the time fruit is setting in the spring. The egg-laying season is of short duration, and temporary wrappers of paper or burlap, or any other material that will entirely cover the lower 2 feet of the trunk for a period of four or five weeks following the blooming season of apple, will in a large measure prevent eggs from being placed on the bark. Treatment with sticky adhesives or heavy paints that are not injurious to the trees will answer the same purpose.

The apple root borers develop freely in the common service tree, and the proximity to apple orchards of woods in which this tree flourishes may always be regarded as a source of possible infestation to the orchard.

PLATE XXIX

Figs. 1 and 3.—Sections of an apple root, showing burrows of the apple root borer (*Agrilus vittaticollis*). About natural size. Original.

Fig. 2.—Cross section of the trunk of a young apple tree, showing burrows made by the larvæ of the apple root borer in ascending the trunk to pupate. Natural size. Original.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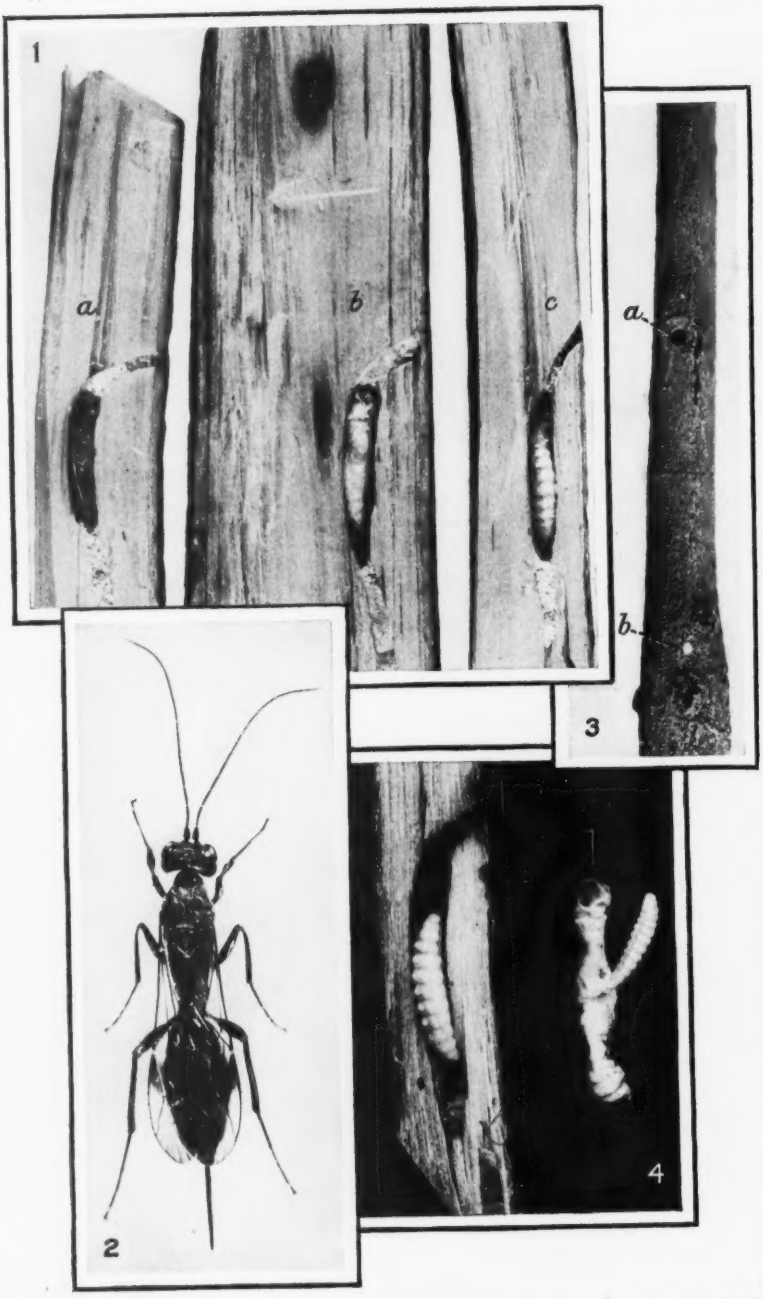
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b
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PLATE XXX

Fig. 1.—*Agrilus vittaticollis:* Larva (*c*), pupa (*b*), and adult (*a*) of the apple root borer in the pupal cell. Slightly enlarged. Original.

Fig. 2.—*Xylophruridea agrili*, a common parasite of the apple root borer. Greatly enlarged; natural size, 18 mm. Original.

Fig. 3.—Section of trunk of young service tree, showing below the white egg and above the exit hole of the apple root borer. Natural size. Original.

Fig. 4.—*Xylophruridea agrili:* Larvæ of the parasite; one feeding on the larva and the other in the pupal cell of its host. Enlarged about one-third. Original.

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PLATE XXXI

Fig. 1.—*Agrilus vittaticollis:* Egg on trunk of young service tree. Original.

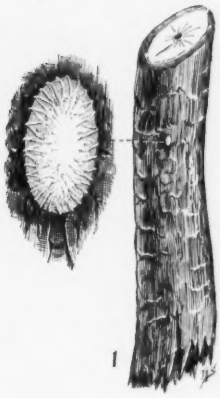
Fig. 2.—*Agrilus vittaticollis:* Feeding form of larva. × 4. Original.

Fig. 3.—*Agrilus vittaticollis:* Contracted form of larva as taken from pupal cell. × 6. Original.

Fig. 4.—*Agrilus vittaticollis:* Pupa. × 8. Original.

Fig. 5.—*Agrilus vittaticollis: a*, Adult, or beetle; *b*, claw; *c*, antenna. *a*, × 5; *b*, *c*, highly magnified. Original.

Fig. 6.—*Xylophruridea agrili*, a parasite of the apple root borer: Pupa. × 8. Original.



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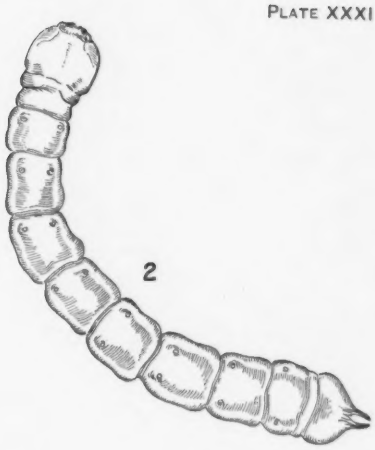

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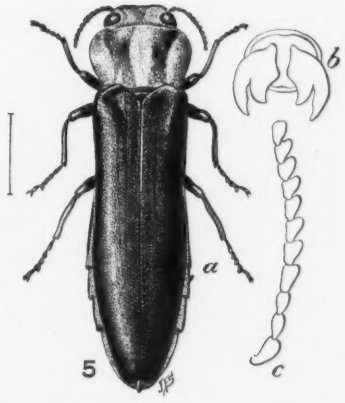

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